NATURAL REGENERATION OR FIRE AND PLANTING: COMPARING TWO BLACK WATTLE REMOVAL AND GRASSLAND RESTORATION APPROACHES IN TROPICAL MONTANE FOREST (SHOLA) - GRASSLANDS IN THE MUNNAR LANDSCAPE, KERALA

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UNDER THE GUIDANCE OF

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Declaration by the student

I certify that

- ➔ The work contained in the thesis is original and has been done by myself under the supervision of my supervisor Dr. Milind Bunyan.
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This is to certify that the work incorporated in this thesis " Natural regeneration or fire and planting: comparing two black wattle removal and native grassland restoration treatments in disturbed tropical montane forest (shola) - grasslands in the Munnar landscape, Kerala " submitted by Akhil Sivadas was carried out under my supervision. No part of this thesis has been submitted for a degree or examination at any university. References, help and material obtained from other sources have been duly acknowledged. I hereby confirm the originality of the work and that there is no plagiarism in any part of the dissertation.

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List of Acronyms

ANOVA	Analysis of Variance
ASNP	Anamudi Shola National Park
BSI	Botanical Survey of India
CAMPA	Compensatory Afforestation Fund Management and Planning Authority
CFP	Cutting - controlled Fire - Planting treatment
CNR	Cutting - Natural Regeneration treatment
CWLS	Chinnar Wildlife Sanctuary
EDC	Eco Development Committee
ENP	Eravikulam National Park
ETP	Exotic Tree Plantations
FAO	Food and Agriculture Organisation
FOI	Flowers of India
GBH	Girth at Breast Height
GBIF	Global Biodiversity Information Facility
GEF	Global Environment Facility
GIS	Geographic Information System
GISD	Global Invasive Species Database
GoI	Government of India
GoK	Government of Kerala
GPS	Global Positioning System
GLAMA	Gap Light Analysis Mobile App
HWC	Human-Wildlife Conflict
IHRML	India High Range Mountain Landscape
IAS	Invasive Alien Species
IBP	India Biodiversity Portal
ILORA	Indian Alien Flora Information
IPC	Industrial Plantation Circle
ISSG	Invasive Species Specialist Group
IUCN	International Union for Conservation of Nature
KDH	Kanan Devan Hills

KDHPC	Kanan Devan Hills Plantations Company
KFRI	Kerala Forest Research Institute
KFWD	Kerala Forest and Wildlife Department
KWS	Kurinjimala Wildlife Sanctuary
KWLS	Kodaikanal Wildlife Sanctuary
MoEFCC	Ministry of Environment, Forest and Climate Change
NABARD	National Bank for Agriculture and Rural Development
NCF	Nature Conservation Foundation
NMDS	Non-metric MultiDimensional Scaling
NP	National Park
NTFP	Non Timber Forest Produce
PA	Protected Area
PIER	Pacific Island Ecosystems at Risk
POWO	Plants of the World Online
PSNP	Pampadum Shola National Park
RET	Rare, Endemic and Threatened
RF	Reserve Forest
RIDF	Rural Infrastructure Development Fund
SAC	Species Accumulation Curve
SGA	State Geographical Area
SRFA	State Recorded Forest Area
SWG	Southern Western Ghats
TGA	Total Geographical Area
TMA	Timber Merchants Association
UNDP	United Nations Development Programme
VCT	Vattakanal Conservation Trust
WG	Western Ghats
WS	Wildlife Sanctuary

Abstract

Afforestation has been a major cause for the loss of open natural grasslands in India. In the Nilgiri and Anamalai-Palani Hills landscapes, tropical montane (shola) grasslands have been historically converted to exotic tree plantations of *Eucalyptus sp.* and *Acacia mearnsii* (black wattle). In the Munnar landscape, the Kerala Forest and Wildlife Department has initiated shola grassland restoration interventions by removing black wattle using different strategies. My study compares two major restoration strategies based on their goals, methods used, costs incurred, the ecological impact in terms of plant species richness, frequency and community composition of native and invasive species, wattle regeneration and faunal activity. I also assessed how the local communities perceive restoration.

I noted that CFP-treated (Cutting, controlled Fire and Planting) sites involved removal of wattle by controlled burning, manual or mechanical felling and planting of grasses and had higher invasion intensity. The CNR treatment (Cutting followed by Natural Regeneration) relied on natural regeneration after manual or mechanical felling of wattle as the invasion intensity was lower. Both treatments included weeding of the regenerated wattle and other invasive species as a maintenance method. I selected two sites for each treatment and used a control (wattle) - treatment (CFP and CNR) - reference (benchmark grassland) sampling design across a total of 40 wattle plots, 20 CFR plots, 22 CNR plots and 12 benchmark grassland plots.

I identified 111 species which included 14 endemic species, 18 exotic species and 15 invasive species. At three years after initiation, CNR-treated sites are more similar to benchmark grasslands in terms of plant species composition compared to CFP-treated sites. The frequency and richness of native grass species and associated herbs is also higher in CNR in comparison to CFP sites. On the other hand, wattle regeneration in CFP is lower than CNR treatment sites and this could be related to the higher efficacy of regular intensive weeding in CFP sites. At the same time, invasive species like *Ageratina adenophora, Pteridium aquilinum, Xerochrysum bracteatum* and *Erigeron karvinskianus* are commonly found in both treatment sites and this indicates that methods to target these species also need to be devised to develop successful site-specific restoration strategies.

While the strongest environmental predictors that differentiated the plant species communities in CFP from CNR and benchmark grasslands were elevation and aspect (eastness), bare soil cover and distance to shola differentiated CNR from CFP and benchmark grasslands. Although treatment sites were more similar to benchmark grasslands compared to wattle plantations, there is considerable overlap between the plant species communities found in wattle and treatment sites. Thus, wattle plantations with a good amount of native species regeneration need not be restored and may be left as they are for natural recovery.

The cost incurred for CFP seems to be very high and 150 % higher than CNR, given the ecological status as of now. At the same time, 80-90% of the cost was transferred to the local community as labour income in both treatments. There is overall a positive perception of restoration. With the return of grasslands in the hills, crop damage due to wildlife in the valley is expected to reduce. But the most critical reason for such a positive perception could be the dominant presence of eucalyptus species like *E. grandis* in the landscape. Even though availability of and access to black wattle for firewood has reduced, eucalyptus has substituted wattle as the most readily available multi-use material resource.

Overall, cost effectiveness of the more active treatment of CFP in terms of the ecological gains due to restoration relative to the socio-economic costs and benefits, is not satisfactory, whereas CNR has shown greater gains with less cost. But further research and long term monitoring and evaluation is required to assess whether CFP has better results in high invasion intensity sites. Restoration and protection of relatively intact grasslands threatened by invasion should be prioritised over conversion of old mature tree plantations to grasslands. Given the degree of dependence on the removed alien and invasive species and aspirations of the local community, their right to participate and decide restoration policies and actions, needs to be recognised.

Chapter 1

Introduction

Invasive alien species not only degrade ecosystems by outcompeting native species and impairing ecological interactions, ecosystem processes and functions, but also threaten them by reducing their geographic extent (Mungi et al., 2019, Ellison et al., 2017). The rampant spread of invasive alien species has led to the degradation of ecosystems and biodiversity loss in many protected areas in India with about 66 % of India's forests suitable for the spread of high concern invasive species and about 22% already invaded by at least one high concern invasive species (Rastogi et al., 2022, Hiremath and Sundaram, 2013). With climate change expected to aggravate these impacts, the focus of a number of global biodiversity conservation forums and conventions has turned to eradicating invasive alien species and restoring native ecosystems. Thus, from a philosophical standpoint, in addition to protection, the idea of ecosystem restoration by removing invasive alien species and assisting the recovery of native biodiversity with an interventional and experimental approach has gained ground in the past decade or so and a number of state-level programmes have been initiated.

The state of Kerala has experienced a policy-driven push to remove exotic tree plantations (plantations hereafter) in the light of recent grassland restoration initiatives in Kodaikanal-Palani and Nilgiris landscapes in the neighbouring state of Tamil Nadu and, the launch of the state ecorestoration policy in 2021. The Kerala Forest and Wildlife Department (KFWD) has embarked on a few ecorestoration projects in the Munnar landscape by removing the invasive alien *Acacia mearnsii* (black wattle) to restore tropical montane (or shola) grasslands. Black wattle was planted by the KFWD for decades until the 1990s, in these grasslands since these were viewed as wastelands. But the species has turned invasive since then. In the Munnar landscape, black wattle plantations cover between 2,122 - 3,200 ha (Sankaran, 2002). Of this, atleast 1468 ha is spread across three protected areas - Pampadum Shola National Park (Pampadum Shola NP hereafter), Anamudi Shola National Park (Anamudi Shola NP hereafter) and Kurinjimala Wildlife Sanctuary (Kurinjimala WS herafter) and about 654 ha are in reserve forests (Lekshmi, 2020). The Munnar Forest and

Wildlife divisions have planned to restore native floral biodiversity and improve the habitat for shola grassland flagship species like the Nilgiri Tahr, Nilgiri Pipit, and the Neelakurinji, by removing 1200 ha of plantations in the current decade 2021-30 (Lekshmi, 2020, Karunakaran, 1998).

Currently, a number of site-specific strategies that involve different methods in the restoration intervention continuum have been initiated by the Munnar Wildlife Division and Forest Division. These include a combination of one or more activities like burning, clear-felling, thinning, planting and weeding. For instance, about 90 ha of black wattle has been removed by controlled burning and felling followed by the planting of native grasses in a number of sites in Anamudi Shola and Pampadum Shola NPs, first in 2015 and then from 2019-20. In Idalimotta and Kurinjimala WS, which has almost 40% of its area under plantations, on the other hand, manual and mechanical removal by clear-felling is ongoing since 2020 (Lekshmi, 2020, UNDP, 2021). A comparative study of these two removal strategies in terms of their costs and the response of native and invasive vegetation is vital to inform long-term invasive species removal and monitoring strategies (Krishnan and Osuri, 2022, Zavaleta et. al., 2001, Cheney et al, 2020). By assessing the efficacy of invasive alien species removal treatments and native grassland restoration, I hope to help develop cost-effective site-specific restoration strategies with predictable, replicable methods and outcomes.

However, ecological restoration must also recognise the rights, needs and aspirations of local people and incorporate these with the considerations of ecology, management and land use dynamics to be inclusive. Inclusive ecological restoration accommodates the communities' perceptions of degradation and restoration in order to make just transitions. In my landscape, both the alien tree species (black wattle, *Eucalyptus sp.*) and the native grasslands have multiple use values for people as fuelwood and fodder. There are two villages - Vattavada and Kottakamboor - which are inhabited by Tamil-origin farmers who reside in the valley largely, and the Muthuvan Adivasi community settled in the hills inside the protected areas. As the removal of plantations and grassland restoration has obvious implications for the local community's wellbeing and their livelihoods and nature-society relationships in general, understanding their aspirations and concerns related to restoration would be useful in assessing the need for such initiatives and making optimal ecological restoration decisions, prioritizations and outcomes.

In this study, I seek to 1) document and compare black wattle removal and shola grassland restoration interventions in the Munnar landscape using a goals-methods-cost framework; and 2) conduct an ecological and socio-economic evaluation of the two restoration approaches in terms of plant species richness and frequency, community composition, wattle regeneration and faunal activity using a control-treatment-reference model and the local community's perception of restoration.

I review the literature and describe my study area and methods in Chapters 2 and 3. I address the two objectives of my study in Chapters 4 and 5 respectively. I synthesize and discuss my findings and recommendations in Chapter 6.

Chapter 2

Review of literature

With about 11,524 sq. km (29.9%) of its geographical area classified as Recorded Forest Area, forest management has always been a critical component of Kerala's governance model. Most of these forests fall in the South Western Ghats Montane Rainforest and Moist Deciduous Forest ecoregions. The former is the most species-rich in South Asia and home to high levels of endemism (Bawa et al., 2007, Chandran, 1997, Nair et al., 2001). Hence, wildlife protection and biodiversity conservation are major cornerstones of forest governance in Kerala. These forests are also the source of almost all the major rivers of the state and play a key role in climate regulation, provide resilience to natural disasters like floods and offer a multitude of cultural and provisioning services to its people, in the form of forest produce, ecotourism and other forest-based livelihoods (Chundamannil, 1993).

However, the goals and objectives of forest management in Kerala and its history have evolved over time based on who had the agency and the needs of the hour. This has meant that nearly two-thirds of the natural forests have been cleared and converted to agriculture, monoculture plantations, human settlements, industries and infrastructure. Most of what remains is fragmented or degraded due to livestock grazing, fuelwood and NTFP collection, encroachment, exotic timber plantations, the spread of invasive alien species and inadequate management measures. This may be correlated to the increasing trend of habitat and biodiversity loss and human-wildlife conflict, and developmental pressures in and around forested areas (Sandilyan, NBA, 2019).

History of forest management and exotic tree plantations

In the late 18th century, before the British gained control over the area that is now Kerala, the regions in the north, Malabar, Cochin, and Travancore, were under different local chieftains. As most of the settlements and trading activities clustered around coastal towns and expanding cultivation to the hills was a strenuous task, the forests of Western Ghats were relatively intact. From the early 19th century, after the British assumed direct rule of Malabar

and established suzerainty over the Kingdoms of Cochin and Travancore, and with the introduction of European foresters and planters, the nature of forestry and forest administration began to change drastically. Accessibility of the forested hills, agricultural land tenure and forest conversions to timber and plantation crops like tea, cardamom, coffee and rubber increased significantly. Expansion in the commercial trade of timber and its use for construction, shipbuilding and railways and firewood necessitated the systematic organisation of timber plantation forestry (Table 3) (Manoharan et al., 2010).

Thus, to secure the sources of timber, firewood and protect water sources in some cases, forests were reserved by enacting laws in all three regions. While the forests of Nilambur, Silent Valley, and Nelliyampathy, among many others, were declared reserved forests with an eye for timber, the Pampadum, Pullaradi, Idivara and Mannavan Shola forests and streams in the Munnar landscape were protected by declaring about 82 sq. km as reserved forests under the Travancore Forest Act (1887) between 1901 and 1908 (KFWD Adm Report, 2021). To secure, organise and regulate the trade in spices, especially cardamom, the Cardamom Hill Reserve (CHR), covering an area of 873 sq. km, was declared in 1887 in the High Ranges. Of this, 556.14 sq. km of land in the Kannan Devan Hills (KDH), which included large swathes of shola forests and grasslands, were leased out to J.D. Munroe, british resident of the Travancore Kingdom, by the Poonjar Raja. Currently, the Kanan Devan Hills Plantations Company (KDHP) covers 237.83 sq. km. of which about 140 sq. km is under tea plantations. The remaining area is under forests and more than 80 sq. km of energy plantations, primarily under different species of the exotic Eucalyptus species introduced and established over time. Red gum (*E. camaldulensis)* plantations were established in 1915 in the Devikulam area of Munnar to provide firewood in revenue land. In the 1940s, this was taken over by the forest department and plantation forestry based on working plans began in a more systematic manner (Malayattoor FD Working Plans, 1952-67).

After independence, the National Forest Policy of 1952 emphasised sustainable timber production and extension forestry to meet the needs of industries, defence and communication. There was a rapid increase in the demand for forest produce from valuable species in the form of timber, pulpwood and other forest-based industrial products all over the country. In Kerala, this resulted in the extensive introduction of acacias (wattles) and more eucalyptus. From 1960-65, the Industrial Plantation Circle (IPC) and the Grassland Afforestation Division (GLAD) focussed on the conversion of ‘unproductive’ areas to

productive timber plantations (Manoharan et al., 2010). In the Devikulam area of the Munnar Forest Division, Eucalyptus, Wattle, Pine and Devikulam Fuel Plantation Working Circles were formed in the 1970s, with an objective to convert grasslands into different plantations. A Social Forestry Wing was formed in 1982 to enhance tree cover outside forests and implement the World Bank-aided Social Forestry Projects that increased the area of timber and pulpwood plantations of teak, acacias and eucalyptus sp. across the state outside forest areas including the Munnar landscape in the next two decades (KFWD Adm. Report, 2021).

Meanwhile, some attention was given to conservation and wildlife protection in certain areas starting from the 1930s. An area of 97 sq. km in the Anamalais, which was KDH land, was preserved as a Nilgiri Tahr game reserve before being declared as the Eravikulam National Park in 1978 under the Wild Life (Protection) Act, 1972. With the prioritisation of forest and wildlife conservation and the regulation of conversion to non-forest activities in the 1980s, the IPC was abolished and these areas were included in the High Range Circle under the newly formed Wildlife Wing (KFWD Adm. Report, 2021).

Even though these efforts succeeded in the preservation and protection of a few forest areas, these continued to undergo ecological degradation. One of the main causes for this was the introduction of exotic plant species, some of which turned invasive. In Kerala, from the beginning of the 20th century and especially since the 1960s, species now classified as the world's worst invasive species like *Acacia mearnsii* (black wattle), *Chromolaena odorata*, *Lantana camara*, *Mikania micrantha* and *Mimosa diplotricha* degraded native ecosystems considerably. The impact of introduced and invasive species, especially *A. mearnsii* and *Eucalyptus sp.* on shola grasslands in the Munnar landscape needs to be understood in this background.

Impact of introduced and invasive plant species on shola grasslands

In the Munnar landscape, the major invaders in the shola forest - grassland mosaic are *A. mearnsii, Chromolaena odorata, Ageratina adenophora, Ageratum conyzoides, Cestrum aurantiacum, Erigeron karvinskianus,* and *Pteridium aquilinum*. The landscape has turned into a mosaic of shola forests, grasslands and plantations of *Eucalyptus sp.*, black wattle and tea. Starting from the 1960s, about 21.23 sq. km. of shola grasslands are now covered by *A. mearnsii* and 29 sq. km. by *Eucalyptus sp.* inside the forest area (KFWD, 2020). This area

forms part of a 380 sq. km area under *E. grandis* and *E. globulus* plantations that have been raised by the KFWD in High Range grasslands since the 1960s (FAO, 1996).

From 1973 to 2017, area covered by shola grasslands reduced by 24% from 214 to 163 sq. km and exotic trees increased from 76 to 117 sq. km in Munnar. In Kurinjimala WS the reduction was from 23 to 5 sq. km (a 78% loss) and from 8 to 2 sq. km (a 75% loss) in Anamudi Shola NP. The change in Kurinjimala WS has been higher and faster (Arasumani et al, 2019). Areas which saw mass flowering of *Strobilanthes kunthiana* (Neelakurinji) had been subject to encroachment and conversion to plantations, resorts and cultivation since the 1990s. Plantations of Eucalyptus and black wattle have been found to be associated with secondary understory invasive species like *L. camara, Ageratina* and *Pteridium sp.* in this landscape with *Eucalyptus* stands showing the highest invasive species richness (Jobin et al, 2022). In addition to the loss in the grassland area, the invasion process also fragments the grasslands, disrupting connectivity.

Shola grasslands have been known to be hosts of several endemic plants and animals. These grasslands are islands of evolutionary diversification of lineages, high species richness and endemicity spread over the montane habitats of the Western Ghats (Joshi et al, 2018). Many species are found only here like the *Rhododendron nilagiricum, Nilgiritragus hylocrius* (Nilgiri Tahr), *Anthus nilghiriensis* (Nilgiri Pipit) and the recently recognised *Sholicola albiventris* (White bellied Sholakili); exhibiting a very narrow range (Robin et al., 2014, 2017). The large-scale conversion of shola grasslands to exotic trees has directly led to habitat loss, further fragmenting their restricted ranges and most of these grassland specialists are listed as Vulnerable or Endangered in the IUCN Red List.

Similarly, the highly competitive nature of *A. mearnsii,* partly due to its ability to produce large amounts of long lived seeds and allelopathic properties, may inhibit the seed germination of native species. This could have aided in replacing vegetation types including grasslands (Zhou et al., 2011). Rise in temperature and reduction in frost frequency and intensity due to climate change, may increase photosynthetic rates in Acacia and Eucalyptus species and enhance their ability to spread into grasslands further (Sukumar et al., 1995, Joshi et al., 2019).

Black wattle has also been shown to impact shola and grassland soils by reducing soil organic carbon, calcium and magnesium and increasing the nitrogen content, pH and conductivity (Prabha et al, 2022, Oelofse et al, 2016). Wattle plantations in Nilgiris were found to have higher overland flow due to infiltration-excess relative to the adjoining shola forests and grasslands, thus increasing flood risks and impacting water cycling (Nayak et al, 2023, Krishnaswamy et al., 2017). They are also known to consume more water, increase transpiration and reduce water availability and streamflow (Henderson and Wells, 1986). In Marayoor near Munnar, evapotranspiration from eucalyptus plantations was recorded to be much higher in comparison to grasslands (Kallarackal, 2010). In the Nilgiris, *E. globulus* (blue gum) plantations in grasslands had lower peak flow, low flow volume, and soil moisture (Sikka et al., 2003).

Eucalyptus sp. and *A. mearnsii* are also known to increase fire hazards. Highly inflammable oil compounds in *Eucalyptus sp.*, and leaves and dead branches in the canopy of black wattle pose a high fire risk during the dry season. In South Africa, increased availability of dry biomass and reduced access to fire breaks due to dense stands has increased fire incidents (de Wit et al., 2001). The study area also witnessed major fire events in 2015 and 2019.

Moving on to social impacts, the unavailability of pastures for livestock has affected people's lives and livelihoods. It also often leads to an association of increased damages due to human-wildlife conflict with the loss of foraging grounds for conflict prone herbivores and other animals. Plantations can also affect access to and availability of NTFPs and traditional community forest resources like medicinal plants and grazing grounds for livestock (Mukwada et al, 2016). The farmers in Vattavada Panchayat associate extensive plantations of Eucalyptus, especially *E. grandis* with a reduction in streamflow, soil moisture, soil fertility and agricultural yield and demand their removal (UNDP, 2021). On the other hand, both species have been used for timber, pulpwood, industrial products like oils and tannin, firewood and building material, and have been a source of income and livelihood for a section of the local community and people from other areas who own these plantations. Black wattle was the primary source of firewood for the local Muthuvan tribe which has been offset to a great extent by *Eucalyptus sp.* now (Kumar, 2017). One could argue that these species have played a role in protecting the native shola forests from being further degraded due to pressures from the local community.

These considerations are vital to incorporate the impacts of restoration on local communities and develop improved policies that go beyond a singular narrative on invasive species that is usually popular among ecologists and policy makers (Reynolds, 2022). The role of traditional socio-ecological knowledge systems and stewardship among the local community in making fair transitions and ensuring sustainability of changes made during restoration interventions, is significant (Cordero et al, 2018).

Degradation and the Practice of Restoration Ecology

Degradation is a state of arrested succession with the impacted ecosystem lacking the ecological process needed for natural recovery. This definition relies on the concept of ecosystem stable states that are pushed to an alternate stable state by drivers or causes that can also create barriers to returning to the original stable state (Ghazoul et al, 2015). Invasive species are often considered tough to control, though area-based conservation using protected areas draws management interventions of higher intensity like restoration (Hoffman, 2022).

International principles and standards for the practice of ecological restoration that highlight steps involved in the process of recovering native ecosystems are currently available (Gann et al, 2019). The control-treatment-benchmark model or the before-after control intervention concept is an important tool for long-term monitoring of restoration outcomes using indicators of biodiversity recovery (Osuri et al, 2019, Mudappa et al, 2014, Raman et al, 2009). A few key indicators are ecosystem structure, species diversity and composition, ecological interactions and the social or economic benefits of the restoration (Holl and Cairns Jr., 2002, Bardgett et al, 2021). The identification and application of the right approach and methods for restoration, including natural regeneration and active restoration, is very important (Crouzeilles et al, 2017). Choosing the right restoration method for an ecosystem, must also move beyond ecological assessments alone to include the human effort, costs and report all aspects of the process including the goals, barrier removal methods, main intervention, preparatory and maintenance methods (Krishnan and Osuri, 2023).

Removal of black wattle and restoration of shola grassland

Different methods of managing *Acacia mearnsii* have been developed and documented based on experiments by the Kerala Forest Research Institute (KFRI) and KFWD (Mol, 2021) and fire can even encourage black wattle invasion potentially (Sriramamurthy et al, 2020). The removal of black wattle seemed to increase the richness and cover of native grassland species in a study in the Nilgiri Biosphere Reserve (Unkule, 2017). Similarly, protection of relatively intact grasslands threatened by invasion sites need to be prioritised over restoration of mature wattle stands (Arasumani et al, 2018, 2019). After removing wattle, removal of other weeds like *Ageratina adenophora, Pteridium aquilinium* and *Rubus sp.* might be necessary to enable natural regeneration of native species (NCF and VCT, 2006). In addition to the application of the right methods, results of interventions can be improved by focussing on the efficacy of implementing methods like felling and weeding (Cheney et al, 2020). Ultimately, cost effectiveness in terms of the gains of restoration relative to cost, is critical and frameworks developed for shola forest-grassland ecosystems need to be followed (Raghurama and Sankaran, 2021).

Thus, the restoration and sustainable conservation of mountain ecosystems and the effective management for multiple uses associated with natural resources in this area is a big challenge. Some of these challenges were addressed; and the restoration projects assessed in this study were initiated, as part of the India High Range Mountain Landscape Project (2018-22) (UNDP, 2013). It attempted to develop site-specific ecosystem restoration protocols that also complement the livelihoods needs of the local community built around plantation crops like tea, eucalyptus, agriculture, tourism etc (Karunakaran et al, 2015).

Chapter 3

Study Area and Methods

Study Area

Tropical montane cloud forest (shola) - grassland mosaics also termed the Shola Sky Islands are found above 1700 m in central and southern Western Ghats. These unique ecosystems have a high degree of endemicity with 48% of Western Ghat endemics finding a refuge here (Robin and Nandini, 2012). In the Nilgiris, Anamalais including Munnar and Palani-Kodaikanal hills, up to 60% of the original area of the shola sky islands have been converted into tea and exotic tree plantations, agriculture and settlements mainly during the 20th century (Arasumani et al., 2019).

My study area is located in the Munnar region of Kerala, a landscape that spans around 1014 sq. km at an elevation range of 1600-2600 m. It is on the eastern or leeward side of Western Ghats forming a catchment of the Pambar river which joins the Amaravathi river, a tributary of Cauvery in Tamil Nadu. In my study sites, the average annual temperature ranges from 5.6-25.1 ℃ with the April-October period being the hottest and December-February, the coldest. The area receives rain from the southwest and northeast monsoons. The average annual rainfall is 992 mm with bulk of the rains falling from May to October, though August to October records maximum rainfall (Lekshmi, 2020).

One of my study sites, Idalimotta, is located on a gently sloping residual plateau to the south of Anamudi Shola NP in the Munnar Territorial Forest Division in Kannan Devan Hills (KDH) of Anamalais. The other three - Pazhathottam, Pattiyankal and Bendar, are located in the Munnar Wildlife Division near Vattavada village, situated further to the east near the Palani Hills (Figure 1). From the late 19th century, the KDH area saw the large-scale conversion of its shola grasslands to tea plantations; currently, the KDH tea plantations span 140 sq. km. More recently, about 25% of shola grasslands in the landscape were replaced by plantations of black wattle (*Acacia mearnsii,*), eucalyptus (*Eucalyptus grandis*) and pine (*Pinus caribaea*) between 1973 and 2017 (Arasumani et al, 2019) (Table 1 and 2).

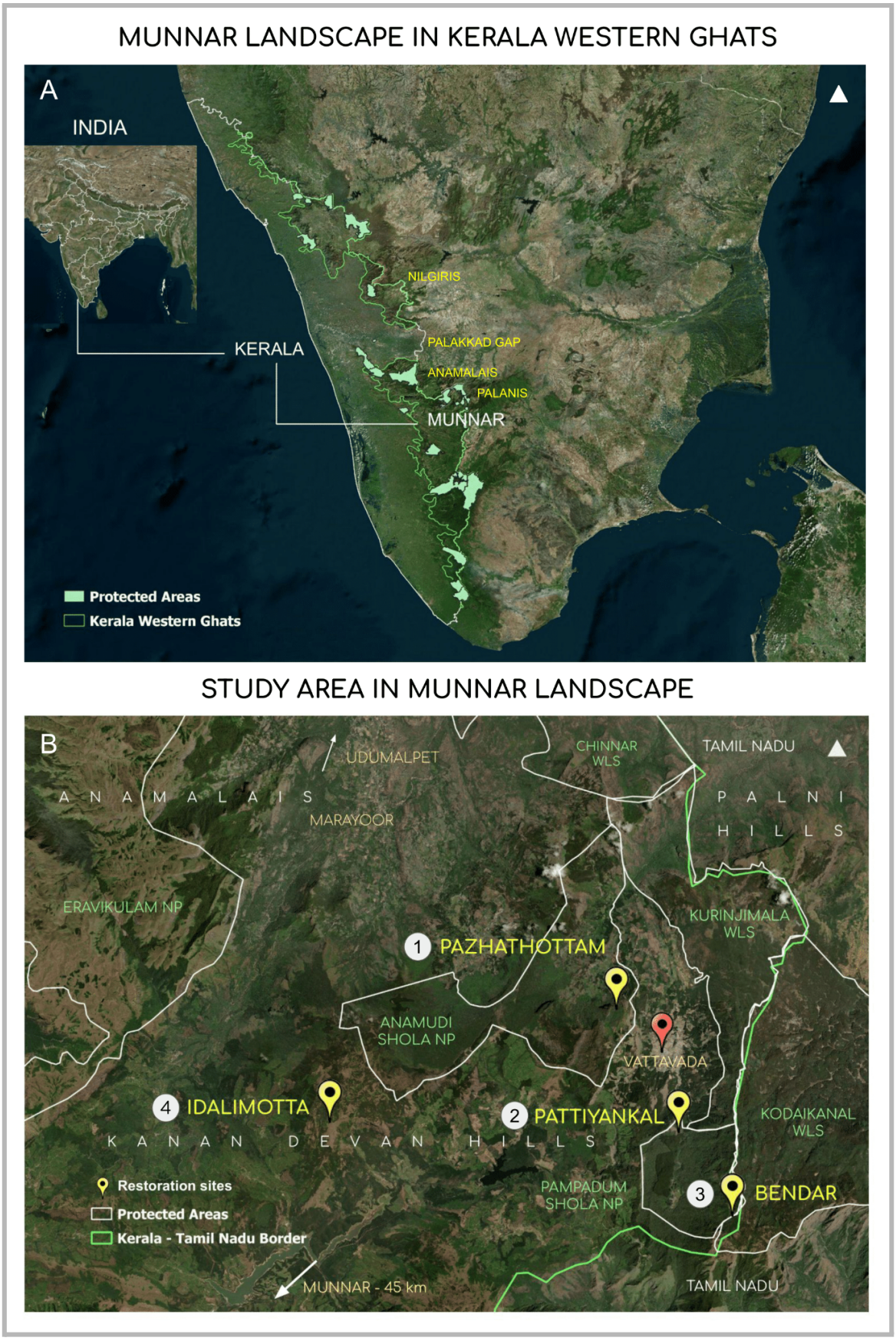

Figure 1. Location of the study area and restoration sites
A - Munnar landscape in the Western Ghats, B - Study area in the Munnar landscape

Forest Division	RF	PR	VF	EFL	PA	Total RFA (sq. km)
Munnar Forest Division (Territorial)	693.53	71.99	2.57	5.14	0	773.25
Munnar Wildlife Division	0	0	0	0	241.07	241.07

Table 1. The extent of Recorded Forest Area in the Munnar landscape
*RF: Reserved Forests, PR: Proposed Reserve, VF: Vested Forest,
EFL: Ecologically Fragile Land, PA: Protected Area

No.	Species Name	Area in SRFA (ha)	Munnar Forest Division (ha)	Munnar Wildlife Division (ha)
1	Eucalyptus sp.	6821.03	2274.44	633.8
2	Acacia mearnsii	2122.57	1468	654

Table 2. The extent of *Acacia mearnsii* and Eucalyptus sp. plantations
in the Munnar landscape

Vegetation composition

The native flora of shola grasslands in the Munnar landscape can be categorised into different communities based on the dominant species present. In Eravikulam, different researchers have suggested varied communities of species like *Chrysopogon nodulibarbis - Arundinella vaginata* (Blasco, 1977), *Eulalia phaeothrix - Sehima nervosum* (Rice, 1984) and *Chrysopogon nodulibarbis - E. phaeothrix* (Sreekumar and Nair, 1991, Karunakaran et al., 1998). From 1900-2500 m elevation in the study area, *Chrysopogon-Cymbopogon* and *Arundinella-Chrysopogon* grassland patches may be found with dominant species like *Chrysopogon nodulibarbis, A. fuscata* and others like *Andropogon polyptychos, S. nervosum* and *E. phaeothrix* (Arigela et al., 2019). Common herbs and shrubs associated with these grasslands are *Anaphalis lawii,* A. *meeboldii,* A. *bournei, Swertia corymbosa, Curculigo orchioides, Ranunculus reniformis,* and *Hypericum mysurense, Strobilanthes sp.* and *Rhododendron arboreum* (Lekshmi, 2020). The most common invasive species in these grasslands are *Ageratina adenophora, Pteriduim aquilinum* and *Acacia mearnsii* (black wattle).

Black wattle

Black wattle is a fast-growing, light-demanding, nitrogen-fixing tree native to southeast Australia that is able to tolerate a wide climatic range from temperate and sub-tropical lowlands to tropical highlands. From coastal areas up to an elevation of 1050 m, they are found at the margins of closed forests and in association with a wide range of Eucalyptus species in Australia (CABI, 2000).

Growing at an average rate of 3 m/year after 3-5 years, they attain a height of 5-15 m and 10-35 cm diameter at breast height and live for an average of 15-20 years. They start flowering from the age of two and produce a large number of long-living hard-coated seeds, that remain viable for 50-100 years with up to 20,000/sq. m. accumulating in the soil seed bank (CABI, 2000). Although black wattle seedlings and saplings are sensitive to fire, mature trees tend to survive in higher proportions. Fire stimulates seed germination by scarification, leading to profuse sprouting of seedlings in burnt areas that increases the stand volume significantly (Pieterse and Boucher, 1997). It is a weak coppicer but shorter stumps coppice readily (Wiersum, 1997).

It is also a commercial plant that has multiple industrial applications and hence, was introduced to and planted along rivers, coastal scrub and grasslands in Africa, Asia, Americas and Europe. In many countries like South Africa and India, black wattle has become invasive. It was planted in Munnar by the KFWD in shola forests and grasslands for products like bark tannin and paper pulp in the 1970s and 80s and has invaded into open grasslands since. The wood is excellent fuelwood and has been used by the local communities in the study area (Lekshmi, 2020, Searle, 1996, 2000, Henderson, 2001). From 2015, the KFWD initiated shola grassland restoration projects by removing black wattle plantations on an experimental basis using different approaches in a few areas under its jurisdiction.

Local community

The Vattavada Grama Panchayat, composed of two villages - Vattavada and Kottakamboor, is located in a valley about 45 km northeast of Munnar near Palani Hills. It is surrounded by the Anamudi Shola NP to the west, Kurinjimala WS to the north and east and Pampadum Shola NP to the south. All these parks were notified from 2003-06 and about 35%

of the PA network is covered by plantations established in the 1960s for timber, tanning bark, pulp and firewood.

The local community is mainly composed of Tamil-origin farmers and the Muthuvan tribe, who are primarily engaged in cold season vegetable and fruit farming. The area is regarded to be moderately drought prone with rising cases of human-wildlife conflict (HWC) due to wild pigs, bonnet macaques, sambar, peacock etc. These communities are dependent on the forest for water and Non-Timber Forest Produce (NTFP) and plantations for firewood, building material and as a source of income. The past decade has witnessed an increase in the number of forest fires that are considered to be man-made, though conclusive evidence is unavailable (Lekshmi, 2020).

I conducted recce surveys and consulted with local forest personnel and project implementation agencies over multiple field visits in February and March, 2023. The Munnar Wildlife Division made its first attempt to remove plantations and restore shola grasslands in 2015 in Pattiyankal (CFP Site 2) after a fire event burnt about 50 ha of black wattle. In 2019, the Division initiated restoration in Bendar (CNR Site 3) which is located along the eastern boundary of Pampadum Shola NP and borders the Kodaikanal Wildlife Sanctuary (Kodaikanal WS hereafter). That year, the Division also initiated its largest single restoration effort in Pazhathottam (CFP Site 1) which extends over 50 ha. In 2020, the Munnar Territorial Forest Division initiated grassland restoration in Idalimotta (CNR Site 4) area of the Munnar Forest Range. In Sites 1 and 2, the Forest Department conducted a controlled burn, clear-felled the burnt trees, weeded unwanted species and planted grasses (CFP treatment). In Sites 3 and 4, the Forest Department clear-felled the trees and relied on natural regeneration and weeding for restoration (CNR treatment).

Methods

My first objective was to study and document the two major grassland restoration interventions used by the Munnar Forest Division and Wildlife Division and compare them based on a framework consisting of goals, barriers to recovery, methods and costs (Krishnan and Osuri., 2023). For this, I reviewed (i) KFWD expert committee reports, policy documents, protected area management plans and forest division working plans, plantation journals, site-specific restoration project proposals and project completion reports, and (ii) research articles and project reports by researchers and subject matter experts and conducted (iii) a secondary data analysis of a peer-reviewed multi-decadal land use change dataset (Arasumani et al. 2019). I also conducted key informant interviews with forest personnel who were involved in the restoration interventions in conceptualisation, design and implementation phases of the project.

My second objective was the ecological and socio-economic evaluation of the grassland restoration interventions by Munnar Forest Division and Wildlife Division. I followed a control-treatment-reference plot design in each site under the CFP and CNR treatments (Nerlekar et al., 2022). At each site, I set up 10 5 x 5 m plots in areas under black wattle and 10 plots where they had initiated grassland restoration. I was unable to determine the ideal sample size for each site beforehand and set up a minimum of 10 plots in each site, increasing this if I had additional time. I also set up benchmark grassland plots as a reference, but these were restricted to Site 3 only since there were no uninvaded grasslands in Site 1, 2 and 4. I used a GIS-based gridded approach to ensure that plots were randomly distributed and separated by a minimum distance of 100 m from each other using QGIS (3.24.0-Tisler; QGIS, 2022) and reduce pseudo-replication. It was ensured that the plots were spread across the site without clustering near the boundaries or in the core, in order to have more independent units.

I used a nested plot design to measure shrubs and trees in a 5 x 5 m plot and grasses and herbs in five 25 x 25 cm quadrats located at the corners and the centre of the 5 x 5 plot (Figure 2). I recorded species abundance and frequency and took photographs to identify species since I was not permitted to collect voucher specimens. In wattle plots, the wattle count was recorded in three GBH (girth at breast height) classes - <= 15 cm, 16-30 cm and >

30 cm. In treatment and benchmark grassland plots, the wattle regeneration count was recorded in three height classes - <= 15 cm, 16-60 cm and > 60 cm. I measured the distance from black wattle and the shola forests for the treatment and benchmark plots, and the distance from the treatment area and shola forests in case of wattle plots (by visual estimation and Google Earth Pro); elevation, slope and aspect using GPS Waypoints (v3.10; Bluecover Technologies, 2023); bare soil cover using visual estimation and canopy cover (only for wattle plots) using GLAMA (v1.3; Tichy, 2016) (Annexures 1, 2, 3 for datasheets) to know whether and how they affect the native and invasive plant species composition across different plot types and the possible implications of these vegetation-environment relationships for the restoration treatment applied (Srinivasan et al, 2015). I conducted fieldwork from April 17th to 25th May, 2023 and collected data from 94 plots (comprising 40 wattle plots, 20 CFP plots, 22 CNR plots and 12 benchmark grassland plots (mostly in S3).

I made regular observations of faunal activity, especially birds and large herbivores in my field journal during plot sampling and in between plots in the control, treatment and reference benchmark grassland plots, using a camera and a binocular and based on interactions with forest field staff.

In sites 1, 2 and 3, I also collected data on local people's perception of these restoration efforts using snowball sampling to conduct open-ended and semi-structured interviews with key informants (n=12) like forest personnel, village and agricultural officers, panchayat ward members and discussions (n=7) with focus groups like farmers (tamil-origin and Muthuvan adivasi), tree plantation workers and daily wage workers engaged in restoration work. I conducted community fieldwork from May 29th to June 9th, 2023.

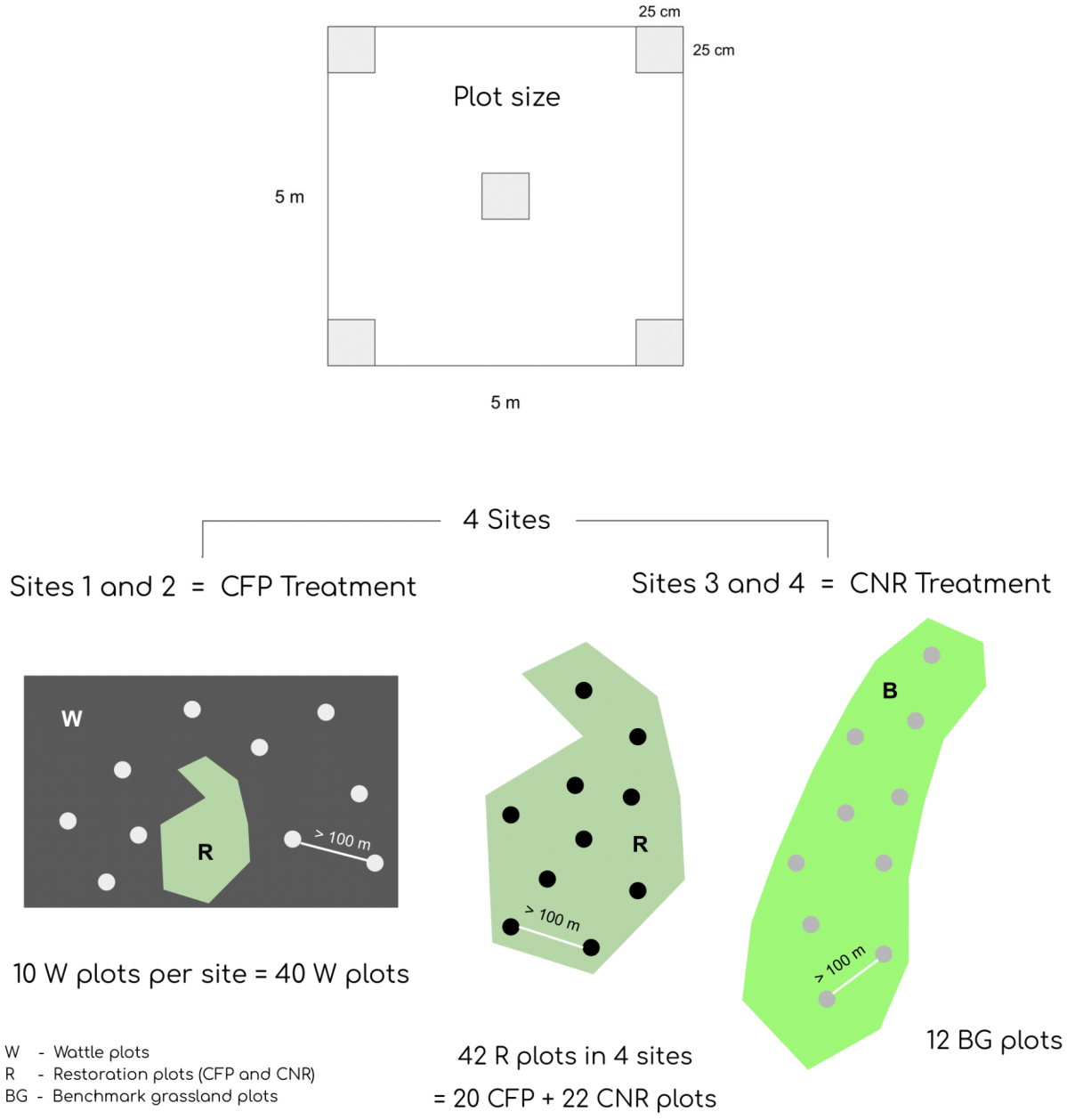

Figure 2. Control-treatment-reference nested plot sampling design

Data Analysis

I relied on subject-matter experts for identifying species using photographs and local names used by community and forest personnel. I supplemented this with suggestions from iNaturalist (iNaturalist, n.d.), PlantNet (Agropolis Fondation, n.d.) and Google Lens (Google Lens, n.d.) for unidentified specimens and verified these suggestions against local species checklists, protected area management plans and research articles. I categorised species into grasses (G), other herbs (H), shrubs (S) and trees (T) to minimise misinterpretation and enable comparison across treatments and noted its status (e.g. native, endemic, invasive) using the IUCN Red List, BSI Red Data Book and other platforms like POWO (Royal Botanic Gardens, n.d.), GISD (ISSG, n.d.), CABI (CABI, n.d.), Sandoval and Pasiecznik, 2022), ILORA (Prajapati et al., 2022), India Biodiversity Portal (IBP, n.d.), and Flowers of India (FOI, n.d.). Species whose frequency in a particular plot type was more than 25% and if not available, the top 25% species in terms of frequency were identified and listed as the most frequent species for each site and plot type.

I used the vegan package (v2.6-4; Oksanen et al., 2022) in RStudio statistical software (v2022.12.0.353; Posit Software, 2022) to assess patterns in species diversity through species accumulation curves and estimating species richness (Gotelli and Colwell, 2001). I used the Kruskal-Wallis test to test for differences in wattle density and wattle GBH class distribution in the wattle plots, and wattle regeneration and wattle height class distribution across different treatments (CFP and CNR) and benchmark grassland plots. I also compared plant species composition across wattle, treatment and benchmark grassland plots by measuring the Bray-Curtis dissimilarity distance (McKight and Najab, 2010) using Non-metric Multidimensional Scaling (NMDS) on the presence-absence data. I used NMDS with an increasing number of dimensions and plotted against stress for each dimension, to get the optimal dimension with the lowest stress. I also used NMDS to assess intrinsic patterns in plant species community composition and its relation to underlying environmental variables using ordination. The selected environmental variables were elevation, aspect (eastness), slope, distance to shola forest, distance to wattle (for restoration plots only), bare soil cover and canopy cover (only for wattle plots).

Chapter 4

Management interventions for shola grassland restoration

The KFWD, based on their field observations and scientific studies, have recognised ecological impacts of plantations including the suppression of native species regeneration, reduction in water and forage availability for animals, facilitation of secondary invasions, the loss of grassland specialist species and negative impacts to local hydrology. Considering the level of disturbance and degradation, expert committees recommended planned interventions to assist the recovery of native ecosystems and achieve time-bound conservation goals (KFWD, 2020). A global push for restoration through international conventions and the availability of CAMPA (Compensatory Afforestation Fund Management and Planning Authority) funds increased funding for local projects. This combined with a rise in human-wildlife conflict and restoration initiatives in similar landscapes (e.g. the Nilgiris, Anaimalai-Palanis) may have also played a key role in promoting restoration policies (e.g. Ecorestoration Policy, 2021) and action in Munnar (KFWD Adm. Report, 2021).

Moreover, the demand for timber, pulpwood and industrial products from forest plantations have reduced consistently and drastically from early 2000s. In 2014-15, the share of wood supplied from forests had reduced to 0.72 % of the total supply. In case of black wattle, the last stand in Munnar was planted in 1998 and there has been no extraction since 1996. The demand for wattle-based tannin reduced suddenly in the 1990s due to the increased import of bark extracts (Anitha et al., 2017). In 2000, the Supreme Court of India in follow-up to the Godavarman judgement, banned the felling and removal of trees for commercial purposes in protected areas. Thus, the management plans of protected areas including Anamudi Shola and Pampadum Shola NPs and Kurinjimala WS prescribed conversion of monoculture plantations to habitats ideal for wildlife as a general policy and have currently started ecorestoration to native shola forests and grasslands. In the Munnar Territorial Forest Division, the wattle plantations near PAs were to be restored to grassland ecosystem and the remaining to be converted to *E. grandis* stands as it still has high demand from the paper and tea industry. Similarly, unproductive eucalyptus plantations were to be converted to indigenous species and those near PAs to shola grasslands. Hence, from a legal

and economic standpoint, the KFWD in Munnar was nudged towards the restoration of black wattle plantations to native ecosystems (Lekshmi, 2020).

Shola grassland restoration in the Munnar landscape

Several experimental interventions on the removal of exotic tree plantations and ecorestoration of shola grasslands have been initiated in Munnar in the past decade. While in the Meesapulimala area, leased out by the KFWD to the Kerala Forest Development Corporation Ltd (KFDC), *Eucalyptus sp.* have been removed for assisted natural regeneration of shola forests and grasslands, in the reserve forests and protected areas of the study area, only black wattle plantations have been restored. I selected four sites to investigate two restoration strategies based on my understanding of the different ecorestoration activities prevalent in my study area. In this section I will (i) give an overview of the four selected sites (Table 3), (ii) compare the two treatments applied using the goals-barriers-methods-cost framework mentioned in the Methods (Table 4), (iii) compare the periodic cycle of restoration activities (Table 5) and the costs incurred for both treatments using Site 1 and 4 as indicative of CFP and CNR treatments, respectively (Figure 3).

Site Number	1	2	3	4
Site Name	Pazhathottam	Pattiyankal	Bendar	Idalimotta
Geography	Anamudi Shola National Park, Anamalai-Palani Hills	Pampadum Shola National Park, Anamalai-Palani Hills	Pampadum Shola National Park, Anamalai-Palani Hills	To the south of Anamudi Shola National Park, Anamalai-Palani Hills
Elevation	2200 - 2400 m	1900 - 2000 m	2400 - 2550 m	2200 - 2500 m
Location	Pazhathottam, Vattavada Panchayat, Munnar	Manathalam, Vattavada Panchayat, Munnar	Vattavada Panchayat, along state border with TN, Kodaikanal WLS to the east	Near Gundumalai Tea Estate Upper Division
Forest Division	Munnar Wildlife Division	Munnar Wildlife Division	Munnar Wildlife Division	Munnar Forest Division (Territorial)
Restoration Treatment	CFP	CFP	CNR	CNR
Restoration Area	25 ha (Total 50 ha marked for ecorestoration)	15 ha (Total ecorestoration area of 27 ha)	Bits or 3, 2 and 1 ha forming 6 ha of ecorestoration area	Bits of 8, 21 and 25 ha
Restoration Period	2020-23 and ongoing	2015-17, 2018-19, 2022	2019-2021	2020-2023
Plantation Details	Black wattle planted in 1975-76 (73 ha), 1977 (80 ha), 1983 (80 ha) and 1991 (10 ha), higher invasion intensity*	Black wattle planted in 1972 (42 ha), 1984, has eucalyptus plantations as well on the eastern side, higher invasion intensity	Black wattle planted in 1972 (42 ha), 1973 (4 ha), 1983 (185 ha), 1991 (60 ha), also pine and eucalyptus plantations, lower invasion intensity*	Black wattle planted in 1991 (10 ha) and 1986, area surrounded by eucalyptus plantations planted from 2008-15, lower invasion intensity

Table 3. An overview of the restoration sites 1, 2, 3 and 4

* older mature wattle plantations and lower native vegetation cover denotes higher invasion intensity, whereas younger plantations with higher native vegetation cover marks lower invasion intensity

Site Number	**1**	**2**	**3**	**4**
Site Name	Pazhathottam	Pattiyankal	Bendar	Idalimotta
Restoration Treatment	CFP	CFP	CNR	CNR
Restoration Goals				
Remove black wattle plantations	✓	✓	✓	✓
Check emerging invasion fronts of black wattle	x	x	x	✓
Restore native grasslands and improve habitat for wildlife	✓	✓	✓	✓
Tourism and revenue generation	✓	x*[1]	x	x
Reduce fire hazards by creating fire breaks	x	x	✓	x
Increase the core zone of the protected area	✓	✓	✓	x
Encourage community participation and create livelihood opportunities	✓	x*[2]	x	x
Barriers to Recovery				
Invasive black wattle fronts around the treatment areas	✓	✓	✓	✓
Benchmark grassland sites are unavailable nearby for seed arrival, establishment and regeneration	✓	✓	✓*[3]	x
Profuse regeneration of black wattle after frequent fire events retard grassland establishment	✓	✓	✓	✓
Other invasive plants like *Pteridium aquilinum* and *Ageratina adenophora* are present	✓	✓	✓	✓

Methods				
Site Preparation				
Nursery raised and for a source of native grass plantings	✓	x	x	x
Main Intervention				
Controlled burning to encourage wattle seed germination and exhaust soil seed bank	✓	✓	x	x
Clear felling wattle stock after controlled burning	✓	✓	x	x
Clear felling wattle stock without controlled burning	x	x	✓	✓
Preliminary weeding of wattle, other invasive species to aid establishment of grasses	✓	✓	✓	✓
Planting native grass species at 2 m spacing	✓	✓	x	x
Ancillary Activities				
Placing burnt logs along contours for soil conservation	✓	✓	x	x*[4]
Placing cut logs as 1 x 1 x 3 m segments in the treatment area (Figure 7)	x	x	✓	x
Maintenance Operations				
Weeding for 3-5 yrs to check regeneration of wattle, other invasive species	✓	x*[5]	x	✓
Supplementary planting if required in case of poor grass establishment	✓	x	x	x
Protection from herbivores by regular patrolling	✓	x	x	✓

Table 4. An overview of the restoration goals, barriers to recovery and methods used for all sites

x*[1] - Although not a goal initially, site 2 is currently used for nature education and as a nature trail for tourists

x*[2] - Although not a goal initially, site 2 promotes community participation as visitors engage in activities like weeding

✓*[3] - Although benchmark grasslands are far, many wattle patches have good natural regeneration of native grasses in site 3

x*[4] - In site 4, logs were moved to the shola boundaries but lighter biomass are contoured in some areas

x*[5] - Weeding is not regular and mostly done through visitors as part of nature education and community participation

Period	Activity	
	Site 1 (CFP)	**Site 4 (CNR)**
Pre-Monsoon (Mar-Apr)	Nursery activities - Irrigation of previous plantings and soil preparation for planting	Site preparation - weeding
	Removal of invasive and exotic weedy species	Clear felling of wattle
	Seed collection for sowing	Weeding of regenerated wattle and other invasive plants
Monsoon (May-Sep)	Restoration activities (planting)	Weeding of regenerated wattle and other invasive plants
	Provision for protection of plantings from herbivores	
	Removal of invasive and exotic weedy species	
Post-Monsoon (Oct-Nov)	Removal of invasive and exotic weedy species	Weeding of regenerated wattle and other invasive plants
	Nursery activities - collection of seeds and grass species	
	Maintenance of planted grasses	
Winter / Summer (Dec-Feb)	Removal of invasive and exotic weedy species	Creation and maintenance of fire lines
	Irrigation of planted seedlings	Weeding of regenerated wattle and other invasive plants
	Nursery activities - seed collection	

Table 5. Periodic cycle of restoration activities to be followed in Site 1 and Site 4

The per hectare restoration costs for the CFP treatment (INR 5.46 lakhs) exceeds the costs for the CNR treatment (2.17 lakhs) by about 150 % (Figure 6). Though the cost incurred for each activity, for example, weeding is not available, it is clear that 80-90% of the cost was used for labour wages.

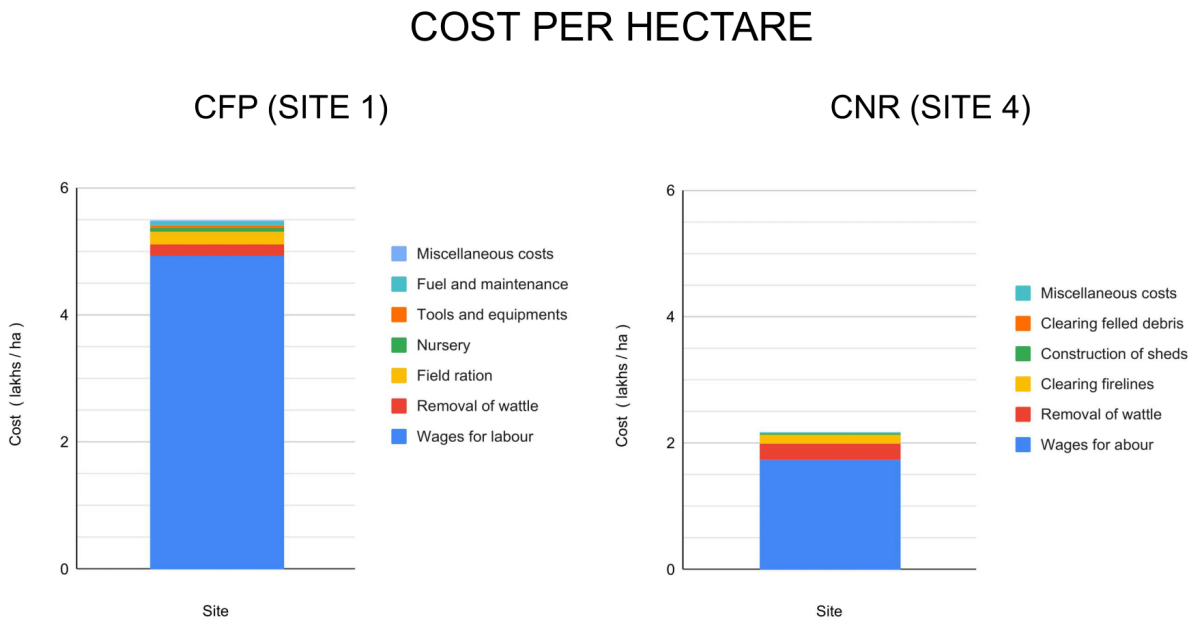

Figure 3. Comparison of cost incurred per hectare between CFP and CNR treatments

Funds for the restoration projects have been allocated from multiple sources. In sites 1 and 4, the projects were implemented under the India High Range Mountain Landscape (IHRML) Project, a collaboration involving the Ministry of Environment, Forest and Climate Change, Government of Kerala and United Nations Development Programme (UNDP) with support from the Global Environment Facility (GEF). In sites 2, 3 and 4, restoration activities have been funded from multiple sources including CAMPA funds, NABARD's Rural Infrastructure Development Fund (RIDF) and other state sector and centrally sponsored schemes for the integrated development of wildlife habitats, and management of protected areas. According to forest personnel, there were differences in the timely release and availability of adequate funds as the sources or the nature of the project varied (project mode or plan schemes for example). This has affected the efficacy of the interventions made in these sites and could have had an impact on the ecological response as well.

Site 1 - Pazhathottam

Figure 4. Top and panoramic view of CFP site 1 - Pazhathottam

In Pazhathottam, an accidental fire event in June, 2019 that razed 50 ha of black wattle, acted as a push to initiate restoration interventions. Based on the successful establishment of planted grasses in a 2 ha area, a strategy was developed. Controlled burning was used to exhaust the wattle soil seed bank, control other invasive weeds and reduce coppice growth in wattle which is usually high in younger (3-5 year old) individuals. The burnt wattle stand area was then clear-felled manually using axes and wood-cutting knives and mechanically using chainsaws when required. The clear-felled burnt logs were aligned along the contours as a soil conservation measure to prevent erosion and possibly because the logs could not be removed due to protected area management restrictions. The regenerated wattle and other non native and invasive species were also removed by weeding just before planting. A nursery was established to raise *Chrysopogon nodulibarbis* and *Cynodon dactylon* for planting by preparing 12 x 1.2 m beds. Fermented cow dung was used as manure and shade was provided for grasses to establish and be ready for transportation to the planting site. Seeds and samples were collected from the nearest benchmark grasslands. Planting was initially done in a 2 ha area and then expanded to the 25 ha area by dividing it into 5 ha zones and planting with *C. dactylon* in pits with a 2 m spacing (Figure 4). In selected areas within each zone, *C. nodulibarbis* was also planted using grasses grown from tillers in the nursery. In order to enhance the establishment of grasses, all identified exotic species and wattle seedlings were weeded out once in two months throughout the year from 2020. Forest watchers were also engaged to protect the planted area from herbivores whenever possible (Lekshmi, 2020).

The total cost incurred from 2020 to 2023 (3 years) under different heads was approximately INR INR 5.46 lakhs/hectare, of which wages for labourers accounted for 90% and remaining was spent on setup, maintenance and running the activity (Figure 5). Thus, it can be seen that a bulk of the cost went into generating income for the local community. From March 2020 to May 2021 when operations began, only 10 workers/day were involved on an average. This increased to about 40 workers for the next two months but then reduced to 19 until November, 2021. The most intensive effort was from December 2021 to September 2022 when an average of 35 workers (with a maximum of 60 for a few weeks) were used; in 2023, that average number reduced to 20. I also noted that it takes about 7 days at approximately 6 hours per day, for 10 labourers to clear a 3-4 year old, one acre stand of black wattle using axes and knives.

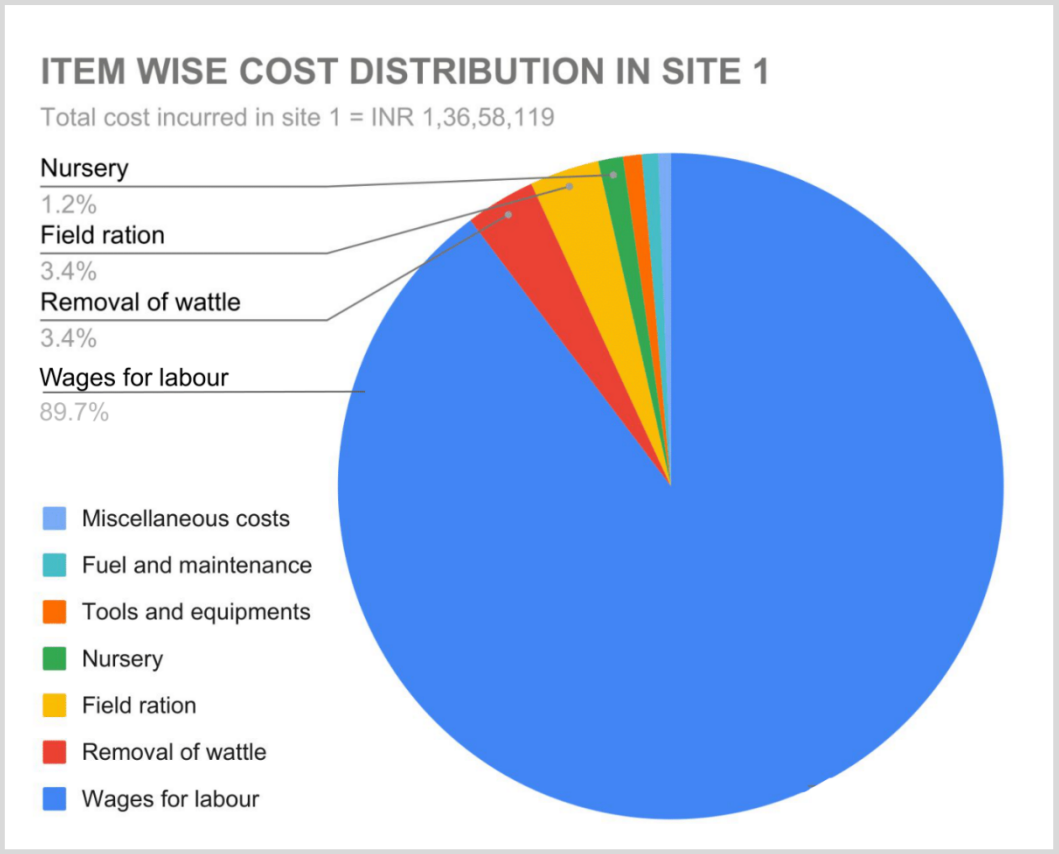

Figure 5. Item wise cost distribution in CFP site 1 - Pazhathottam

Site 2 - Pattiyankal

Figure 6. Top and panoramic view of CFP site 2 - Pattiyankal

In the Pattiyankal site, after accidental fire incidents in 2015 were arrested, a 15 ha area of the burnt wattle stand was clear-felled manually. The entire area was burnt to encourage wattle regeneration from the soil seed bank and eradicate other invasive plant species. The burnt logs were aligned along the contours as a soil conservation measure and possibly because the logs could not be removed due to protected area management restrictions. An intensive removal of the regenerated wattle and other non native and invasive species was carried out to prepare the soil for natural regeneration of the desired species. *Digitaria sanguinalis* was planted for rapid spread of grass cover and they were planted randomly without any regular spacing. A few *Chrysopogon* species were also planted on a trial basis which successfully established in most areas. In order to enhance natural regeneration and establishment of grasses, all identified exotic species and wattle seedlings and coppices were weeded out but in an irregular manner using volunteers from schools, colleges and civil society organisations, as a part of nature education camps organised by the Munnar Wildlife Division.

The major restoration activities were done from 2015 to 2017 with occasional maintenance after that, but details are not available as these were conducted on an experimental basis (Figure 6). Black wattle has also been removed by clear-felling and controlled burning (CNR treatment) in another neighbouring patch from 2018-2022, but these areas were not included in the sampling.

Site 3 - Bendar

Figure 7. Top and panoramic view of CNR site 3 - Bendar

In Bendar, the wattle plantations were clear-felled using chainsaws and the heavier dead biomass was cut and stacked into billets of 1 x 1 x 3 m segments in the site itself as protected area management restrictions prohibited removal. Initial weeding of the regenerating wattle and other non native and invasive species was carried out to prepare the soil for natural regeneration. Weeding of all identified exotic species, wattle seedlings and coppiced shoots was carried out once after initial weeding, but maintenance weeding is rarely practised due to logistical constraints (Bendar is eight kilometres inside the National Park) and also because there is good natural regeneration of grasses (Figure 7).

15 mazdoors were employed and they used motorised chainsaws to clearfell the black wattle but costs were not available for these activities. Clear-felling was carried out from February-April, 2021 to create tree breaks and aid the natural regeneration of grasses in the 3 ha restoration area; this area was the main focus of my sampling in this site.

Site 4 - Idalimotta

Figure 8. Top and panoramic view of CNR site 4 - Idalimotta

In Idalimotta, the wattle plantations and invaded grasslands were clear-felled in 2020 using chainsaws (Figure 8). The heavier biomass was removed using earthmovers that pushed these into the shola forest valleys and the lighter dried branches were arranged along the contours. In very few cases, the lighter dried biomass was piled up and burnt but this was generally discouraged. Removal of regenerating wattle and other non-native and invasive species was carried out to prepare the soil for natural regeneration; clear-felling was expected to assist natural regeneration of native grass species. In order to enhance the natural regeneration and establishment of grasses, weeding of all identified exotic species and wattle seedlings and coppice growth was carried out every two months throughout the year for three years. Even though maintenance weeding was planned for five years, I noted that weeding has not been done since 2022.

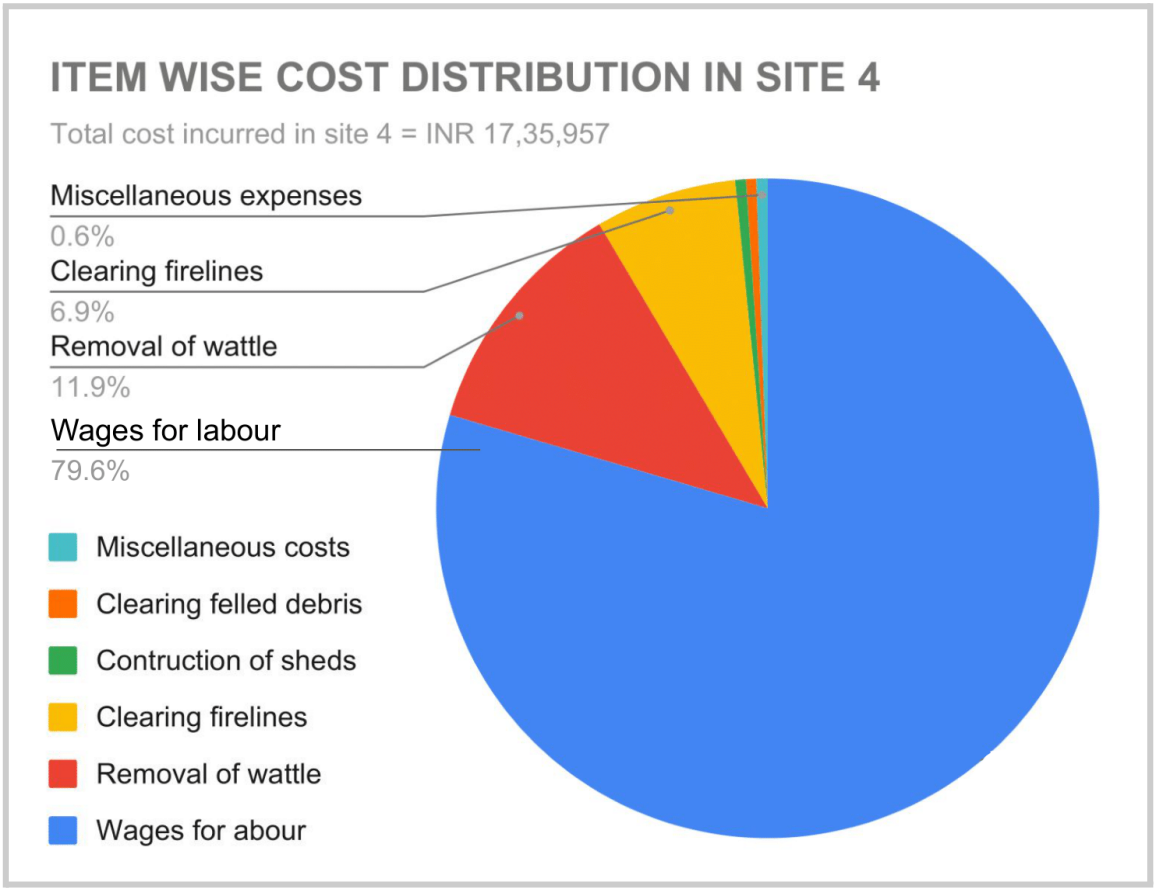

Figure 9. Item wise cost distribution in CNR site 4 - Idalimotta

The total cost incurred from 2020 to 2023 (3 years) is approximately INR 2.17 lakhs/hectare. The labour costs for regular maintenance weeding accounted for 80% of all costs, which will only increase considering the labour costs of other activities (Figure 9). The list of activities and degree of cost and effort for the 21 and 25 ha areas are also similar on a per hectare basis, but were not available during the study.

Clear felling of the 1991 wattle plantation was initiated in April 2020 using chainsaws and earthmovers and the remaining were removed with chainsaws and manual labour in May and June, 2021. At the same time, from May 2021, the site was prepared to assist natural regeneration by weeding wattle regeneration and other exotic or invasive plant species. An average of 4 mazdoors were engaged for 200 days in a year for maintenance weeding and other activities. This shows that the intensity of weeding here was lower in comparison to Pazhathottam (CFP Site 1).

Thus, in conclusion, I noted that while removal of black wattle and restoration of native grasslands was the major goal across sites, community participation and livelihood generation was a goal only in Pazhathottam (CFP Site 1). In Pattiyankal (CFP Site 2), the restoration project was initiated in 2015, four years before all the other sites, on an experimental basis. Although barriers to recovery of grasslands like presence of black wattle invasion fronts, wattle regeneration due to accidental fires, and other invasive species taking over wattle cleared areas were common across sites, I noted that benchmark grasslands were available near Bendar and contiguous to restoration areas in Idalimotta (CNR sites 3 and 4). The common methods across both treatments, CFP and CNR, were preliminary weeding (all sites) and maintenance weeding (CFP Site 1 Pazhathottam and CNR Site 4 Idalimotta). But the intensity, frequency and number of weeding years was higher in the CFP site compared to the CNR site, due to the availability of extra funds for weeding as fire was expected to cause profuse regeneration of wattle in CFP treatment. In Pattiyankal (CFP Site 2), the regularity of restoration activities was affected by the inconsistent availability of funds and change in management over the eight years since its initiation. In Pattiyankal (CFP Site 2) and Bendar (CNR Site 3), cost details were not available as they were not carried out in a single project mode as was the case in Pazhathottam (CFP Site 1) and Idalimotta under the IHRML project (CNR Site 4).

Chapter 5

An ecological and socio-economic evaluation of different restoration interventions

The assessment of the ecological response across CFP and CNR treatments included 1) Species identification; 2) Species-area and species accumulation curves for sampling adequacy and species richness estimation; 3) Native, non-native and invasive species frequency comparison across wattle, CFP, CNR and benchmark grassland plots; 4) Comparison of plant community composition and effect of environmental predictors across wattle, CFP, CNR and benchmark grassland plots using ordination techniques and finally, 5) Black wattle density and regeneration across wattle, CFP, CNR and benchmark grassland plots. I have also compared the control wattle plots across sites to demonstrate differences in plant community composition and wattle density, 6) Observations on faunal activity. The socio-economic evaluation included a study of local community perceptions about these restoration efforts and the removed / restored species and ecosystems.

I recorded a total of 196 potential species in the wattle, treatment and benchmark plots by grouping species according to visual features and plant habit that I observed during data collection (Figure 7). I cleaned and divided these into grasses, rushes and sedges (G; 28 species), other herbs (H; 131 species), shrubs (S; 14 species) and trees (T; 23 species) for identification and analysis. I identified a total of 111 species (22 to the genus), comprising 11 grasses, 73 herbs, 15 shrubs and 12 trees. These included 14 endemic species, 18 exotic species and 15 invasive species (Figure 14). Two species which are not native to shola grasslands (*Cynodon dactylon* in Site 1 and *Digitaria sanguinalis* in Site 2) were planted during restoration. The complete list of identified species is provided in Annexure 4.

Inferences from Species Area Curves

I noted 16 grasses, 64 herbs, eight shrubs and 17 trees in my wattle plots (n=40). I also recorded a number of grass species although this varies across and within sites. The species-area curve suggests that I have recorded most of the grasses, shrubs and trees, but

additional sampling is required for the herbs (Figure 10). I noted 10 grasses, 31 herbs, 6 shrubs and 4 trees in my CFP treatment plots (n=20) and 18 grasses, 66 herbs, 10 shrubs and 12 trees in my CNR treatment plots (n=22). Here too, the species-area curve suggests that additional sampling might be required to record all herbs, whereas the grasses, shrubs and trees have been sampled adequately (Figure 11 and 12). In my benchmark plots (n=12), I noted 13 grasses, 56 herbs, five shrubs and three trees. Other than *Rhododendron arboreum*, I only recorded exotic trees like black wattle, eucalyptus and pine in these plots (Figure 13).

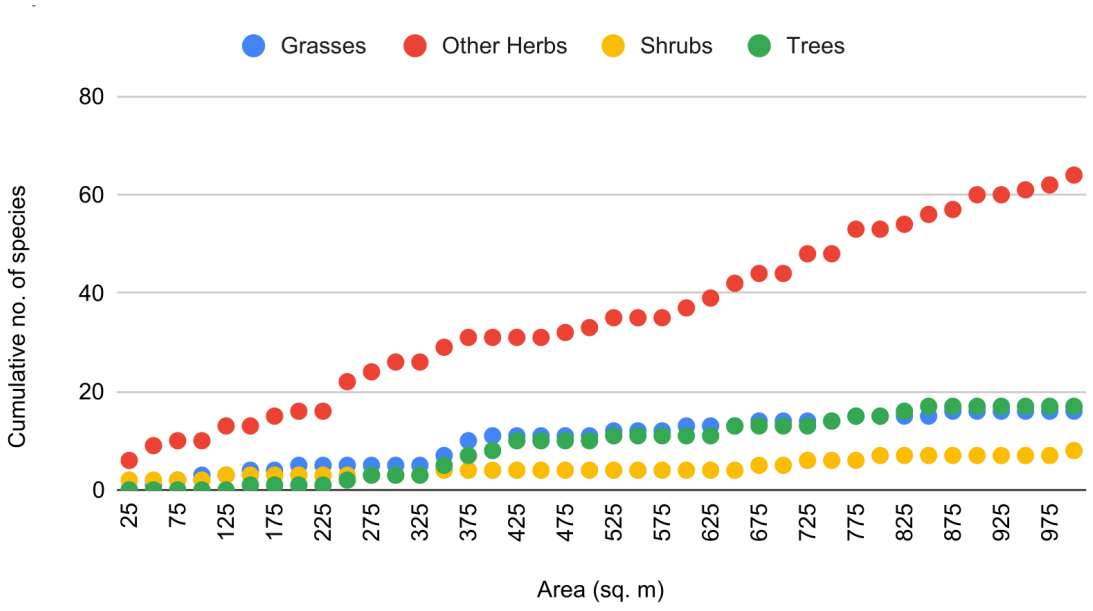

Figure 10. Species - Area Curve in wattle plots

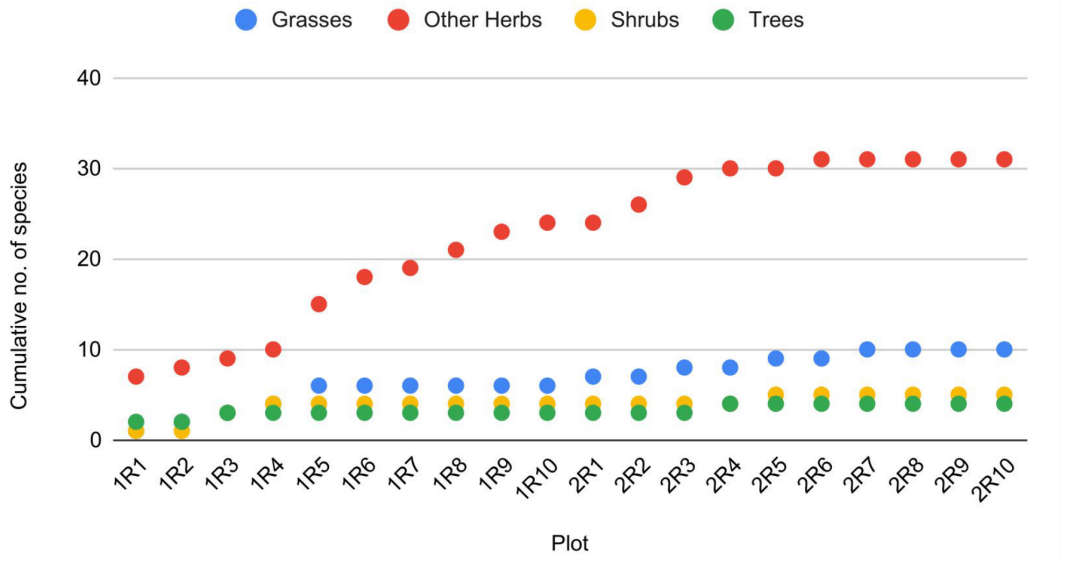

Figure 11. Species - Area Curve in CFP treatment plots

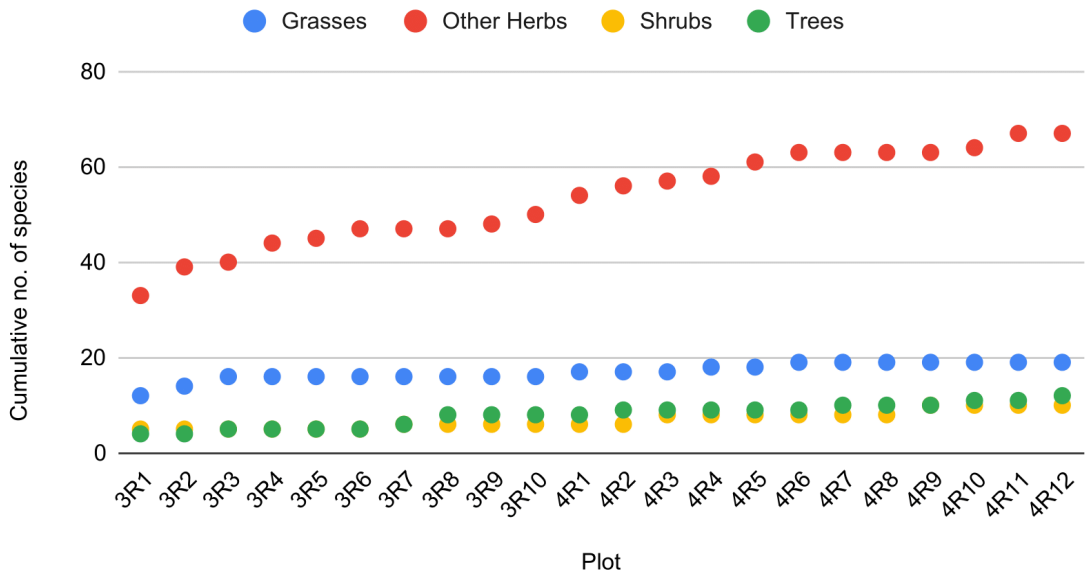

Figure 12. Species - Area Curve in CNR treatment plots

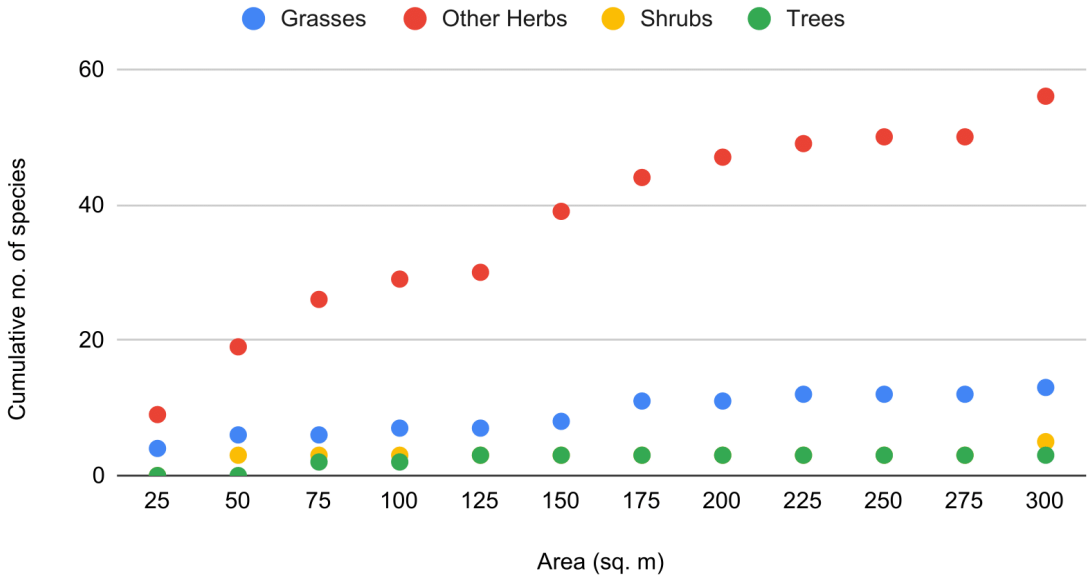

Figure 13. Species - Area Curve in benchmark grassland plots

Figure 14. A few species in flowering stage from the field

1 - *Cyanotis arachnoidea,* 2 - *Commelina hirsuta,* 3 - *Commelina indehiscens,* 4 - *Pseudognaphalium hypoleucum,* 5 - *Indigofera prostrata,* 6 - *Striga asiatica,* 7 - *Aristea ecklonii,* 8 - *Brachycorythis wightii,* 9 - *Justicia simplex,* 10 - *Polygala sibirica,* 11 - *Leucas ciliata,* 12 - *Impatiens tangachee*

Inferences from Species Accumulation Curves

I noted substantial variation among sites for wattle and treatment plots but the number of species was consistently lower in CFP-treated sites 1 and 2. There is a stark difference between species richness in wattle plots of sites 1 and 2 (31 and 42 species respectively). Conversely, CFP-treated plots in site 1 have higher species richness than site 2 (36 and 24 species respectively) (Figures 15A, 15B). Benchmark grassland plots also had consistently more species than all treatment plots. Treatment plots were projected to support the most species (108 species, Table 8), which was 30% higher than the benchmark grassland plots (77 species). The species accumulation curve predicted fewer species (52 species) in CFP treated plots than the benchmark grassland plots (77 species). Across wattle and treatment plots, and CNR and CFP treatments, the species accumulation curves appear to be flattening, but for the benchmark grassland plots, they were not, which could be because of fewer plots sampled (n=12) (Figure 15C). It has to be noted that the species richness count here includes alien and invasive species as well, in addition to the native species.

	No. of plots	Species Richness Estimate (SAC)
Plots		
Wattle	40	105
Treatment	42	108
Benchmark	12	77
Treatments		
CFP	20	52
CNR	22	83

Table 6. Estimates of species richness in wattle, treatment and benchmark grassland plots

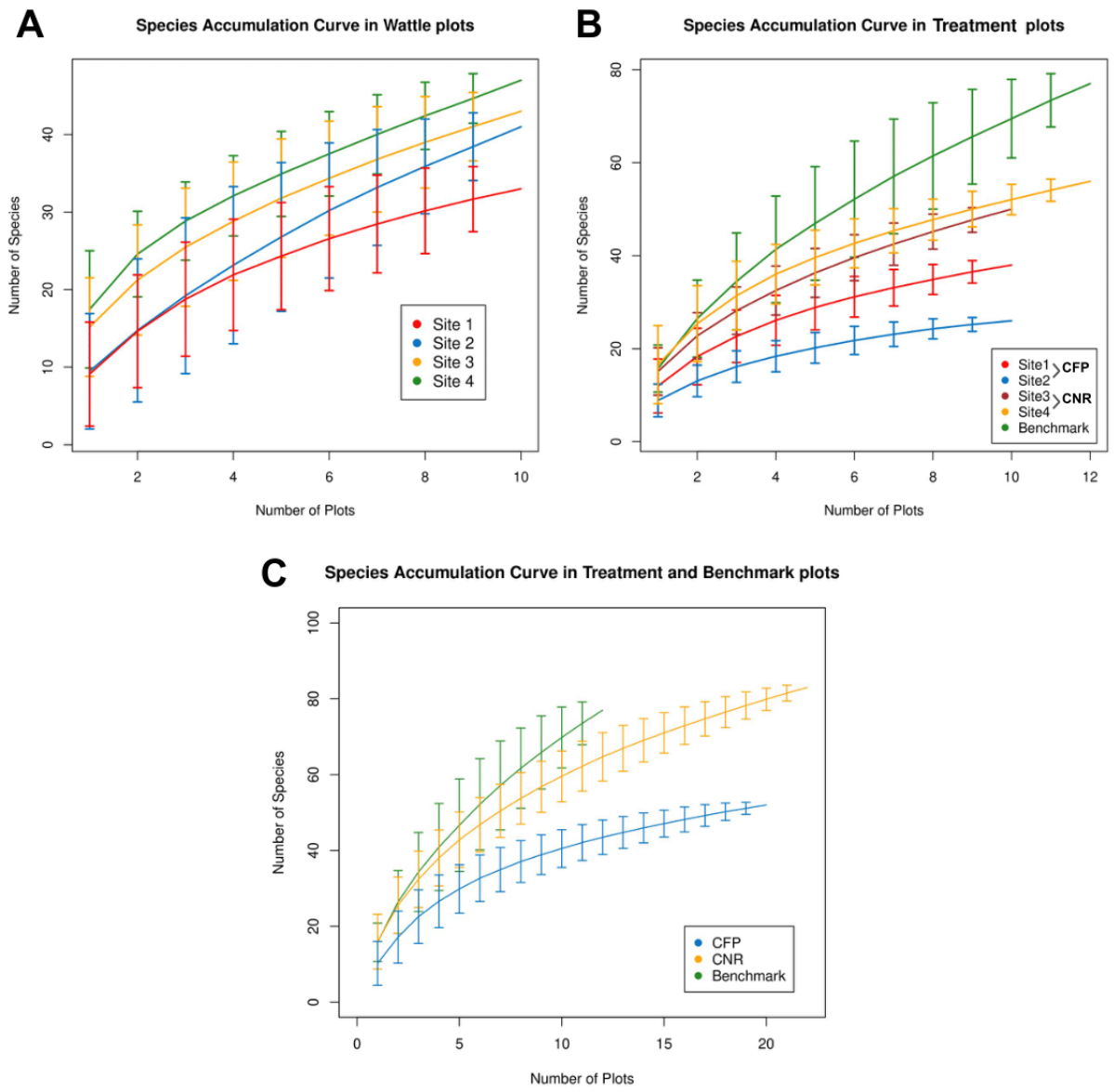

Figure 15. Species Accumulation Curves for A) wattle plots site-wise B) treatment plots site wise and C) treatment and benchmark plots

Species Occurrence across Plots and Treatments

Among native species in the control wattle plots, *Isachne kunthiana* was encountered the most (0.925) and the most widely distributed. *Chrysopogon nodulibarbis* (0.325) was common especially in the wattle plots around CNR-treated sites 3 and 4. Other common species were *Eragrostis nigra, Curculigo orchioides, Cyperus flavidus* and *Solanum sp. (violaceum* ?), *Dandelion sp., Hypericum mysorense* and *Laurembergia coccinea*. *Rubus ellipticus,* which is a native of shola margins (declared as invasive in a few countries) that tends to spread fast in cleared sites in the study area and hence is sought to be removed, was also very common in the wattle plots (0.575) (Table 9). Two Western Ghats endemics *Mahonia leschenaultia* and *Neolitsea scrobiculata* (7 and 5 out of 40 plots) and species like *Zanthoxylum asiaticum* and *Syzygium sp.* associated with shola forests were also found. *Eragrostis viscosa* is a species not native to shola grasslands that was found the most frequently. Among invasive species, *Ageratina adenophora* was found in 32 of 40 plots. The other common invasives are *Erigeron karvinskianus, Pteridium aquilinum* and *Oxalis corniculata*.

In CFP-treated plots, *Eragrostis viscosa* was encountered the most (0.9) and the most widely distributed, followed by *Xerochrysum bracteatum* among native species. In addition, *Eragrostis nigra, Isachne kunthiana, Xerochrysum bracteatum, Ranunculus reniformis* and *Chrysopogon nodulibarbis* were the most frequently seen. *Rubus ellipticus* was also found in 6 out of 20 CFP plots (Table 9). A Western Ghats endemic *Ranunculus reniformis* was also seen reasonably often (frequency = 0.3). Among invasive species, *Ageratina adenophora* was found in all the plots. The other common invasives are *Ageratum conyzoides, Pteridium aquilinum* and *Oxalis corniculata. Acacia mearnsii* was found at a frequency of 0.6. *Erigeron karvinskianus* was seen less frequently compared to wattle, CNR and benchmark grassland plots.

Species Name	Endemicity	Habit (G/H/S/T)	Frequency			
			W	CFP	CNR	BG
NATIVE / ENDEMIC						
Anaphalis meeboldii	WG	H	0.025	0.000	0.364	**0.667**
Anaphalis subdecurrens	WG-SL	H	0.025	0.200	0.318	0.250
Cajanus rugosus		H	0.000	0.000	0.000	0.417
Chrysopogon nodulibarbis		G	0.350	0.300	**0.682**	**0.833**
Commelina indehiscens	WG	H	0.000	0.000	0.000	0.333
Curculigo orchioides		H	0.475	0.000	**0.864**	**0.583**
Cyanotis arachnoidea		H	0.000	0.150	**0.500**	**0.583**
Cyperus flavidus		G	0.475	0.200	**0.500**	0.000
Eleocharis congesta		H	0.075	0.000	0.318	0.333
Emilia sonchifolia / scabra		H	0.000	0.250	0.136	0.000
Eragrostis nigra		G	**0.500**	**0.500**	**0.636**	0.083
Gynura nitida	WG	H	0.000	0.000	0.000	0.333
Hypericum mysorense		H	0.200	0.000	0.364	0.417
Isachne kunthiana		G	**0.925**	**0.500**	**0.773**	0.167
Laurembergia coccinea		H	0.200	0.000	0.409	0.167
Mahonia leschenaultia	WG	T	0.175	0.000	0.095	0.000
Micromeria imbricata		H	0.025	0.000	0.136	**0.667**
Neolitsea scrobiculata ?	WG	T	0.125	0.000	0.000	0.000
Osbeckia leschenaultiana	SWG	S	0.000	0.000	0.182	**0.833**
Polygala sibirica		H	0.000	0.000	0.000	0.250
Ranunculus reniformis	WG	H	0.075	0.300	0.136	0.250
Rhododendron arboreum	SWG	S	0.000	0.000	0.136	**0.500**
Rubus ellipticus		S	**0.575**	0.300	**0.591**	0.083
Strobilanthes kunthiana	WG	S	0.000	0.000	0.045	0.167
Syzygium sp.		T	0.175	0.050	0.095	0.000
Viola betonicifolia		H	0.000	0.000	0.045	0.333
Wahlenbergia		H	0.000	0.000	0.000	0.250

Species Name	Endemicity	Habit (G/H/S/T)	Frequency			
			W	CFP	CNR	BG
marginata						
Zanthoxylum asiaticum		H	0.125	0.000	0.045	0.000
ALIEN						
Eragrostis viscosa		G	0.350	**0.900**	0.250	0.000
Eucalyptus sp.		T	0.075	0.150	0.024	0.083
Pinus sp.		T	0.050	0.000	0.000	0.250
Xerochrysum bracteatum		H	0.000	0.350	0.000	0.000
INVASIVE ALIEN						
Acacia mearnsii		T	**1.000**	**0.600**	**0.909**	0.250
Ageratina adenophora		H	**0.800**	**1.000**	**0.500**	0.333
Ageratum conyzoides		H	0.050	**0.500**	0.091	0.083
Erigeron karvinskianus		H	**0.550**	0.150	**0.636**	**0.583**
Oxalis corniculata		H	0.225	0.350	0.227	0.000
Pteridium aquilinum		H	0.450	0.350	**0.545**	**0.500**

Table 7. Most frequently encountered species across plots and treatments
SL: Sri Lanka; SWG: Southern Western Ghats; WG: Western Ghats
BOLD: Frequency >= 0.500

In CNR-treated plots, *Curculigo orchioides, Isachne kunthiana, Chrysopogon nodulibarbis, Eragrostis nigra* and *Cyperus flavidus* were encountered the most (above 0.5) and the most widely distributed among native species. The other commonly seen species were *Cyanotis arachnoidea, Laurembergia coccinea, Anaphalis beddomei,* A. *meeboldi, Hypericum mysorense* and *Eleocharis congesta*. Other endemics like *Osbeckia leschenaultiana* and *Rhododendron arboreum* were also seen. While 23 of the most frequent species were native or endemic in CNR, only 10 of these were common in CFP. *Rubus ellipticus* was also found in 13 out of 22 CNR plots. *Eragrostis viscosa* is a species not native to shola grasslands that was found the most frequently. Among invasive species, *Erigeron karvinskianus, Pteridium aquilinum* and *Ageratina adenophora* were the most frequently seen. *Acacia mearnsii* was found at a frequency of 0.9, much higher than in CFP (0.6). While A. *adenophora, Ageratum conyzoides* and *Oxalis corniculata* were less frequent in CNR

compared to CFP plots, the frequency of *Erigeron karvinskianus* and *Pteridium aquilinum* were similar in CNR and CFP plots (Table 9).

In the reference benchmark grassland plots (Figure 16), the most common native species were *Chrysopogon nodulibarbis, Curculigo orchioides, Commelina indehiscens, Leucas aspera* (?), *Cyanotis arachnoidea* and *Micromeria parviflora* (above 0.5). *Anaphalis meeboldii, Hypericum mysorense, Cajanus rugosus, Viola betonicifolia, Gynura nitida, Eleocharis congesta, Anaphalis subdecurrens, Ranunculus reniformis, Polygala sibirica, Wahlenbergia marginata, Osbeckia leschenaultiana, Rhododendron arboreum* and *Strobilanthes kunthiana* were also quite common in that order. While 22 native and / or endemic species were recorded in the benchmark grassland plots relative to CNR (23), their frequency is much higher in benchmark grasslands. Among invasives, *Erigeron karvinskianus* and *Pteridium aquilinum* were the most common and frequency was comparable to the treatment plots. The frequency of all other invasive species like *Acacia mearnsii, Ageratina adenophora* (0.33), *Ageratum conyzoides* and *Oxalis corniculata* were much lower compared to the wattle and treatment plots (Table 9).

Figure 16. The benchmark grassland patch that was sampled near Bendar restoration site

Plant Community Composition and the Effect of Environmental Predictors

The NMDS ordination plots reveal that the plant communities in wattle plots across sites 3 and 4 were reasonably similar and contained more native grasses, but sites 1 and 2 were more dissimilar. Site 2 is physically further away from the other sites, which might explain its dissimilarity (Figure 17). Elevation and bare soil cover were strongly correlated with the community composition patterns and aspect (eastness) is negatively correlated with elevation. In Site 2, most of the wattle plots are on the east facing slopes, potentially influencing species composition. In Site 1, bare soil cover and distance to shola appear to influence community composition.

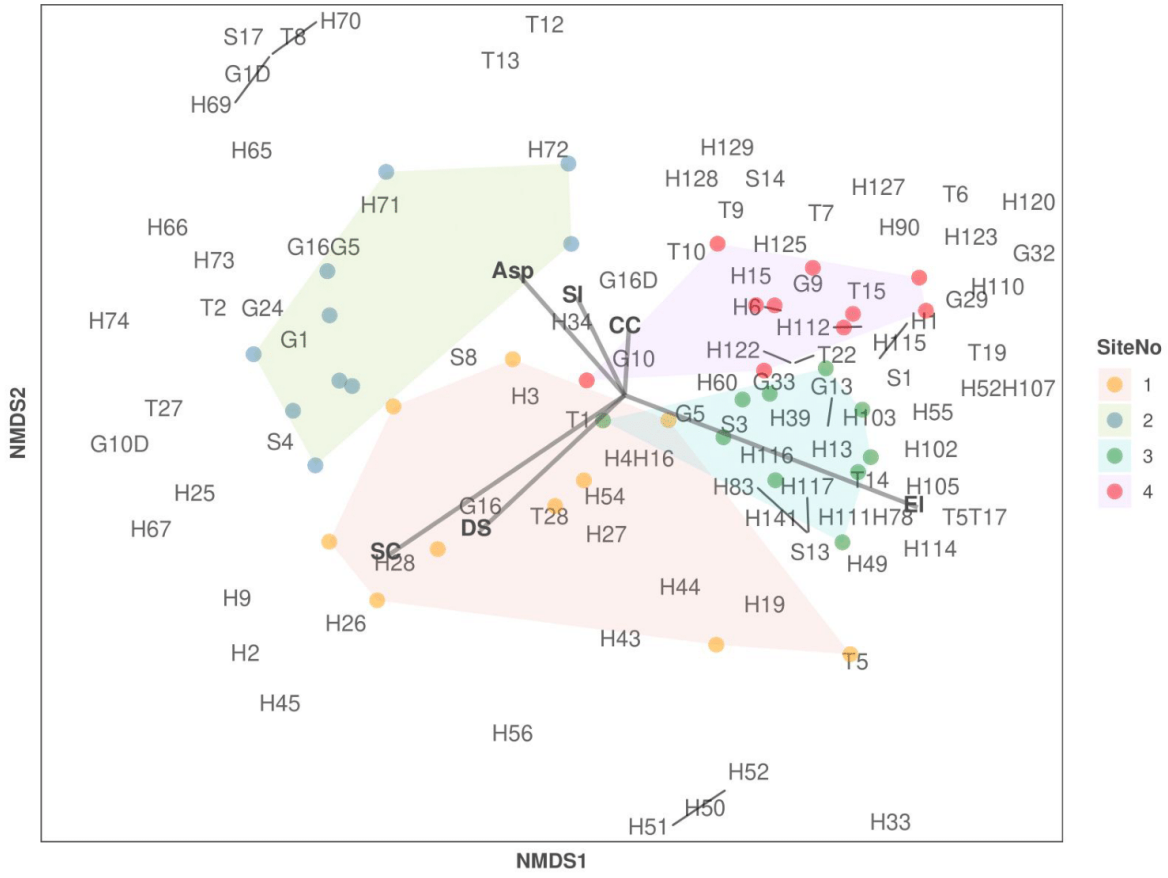

Figure 17. NMDS ordination of plant communities in wattle plots with environmental predictors
El: Elevation, Asp: Aspect (Eastness), Sl: Slope, SC: Bare Soil Cover, DS: Distance to Shola, CC: Canopy Cover

I also noted that Site 2 was compositionally dissimilar when considering treatment plots and that sites 3 and 4 contained more native grasses (Figure 18). Elevation, aspect (eastness) followed by distance to shola were strongly correlated with the community composition in the treatment plots. This pattern might reflect the location of most treatment plots on east-facing slopes in Site 2.

Figure 18. NMDS ordination of plant communities
in treatment plots with environmental predictors
El: Elevation, Asp: Aspect (Eastness), Sl: Slope, SC: Bare Soil Cover,
DS: Distance to Shola, DW: Distance to Wattle

I noted that the species composition in CFP plots was distinct from CNR plots, but CNR plots were compositionally similar to benchmark grassland plots. I also observed that the CNR plots were compositionally richer than the CFP plots, reflecting my observations from the species accumulation curves (Figure 19). Elevation is strongly correlated with species community patterns across treatments followed by distance to wattle and aspect (eastness). Elevation and aspect (eastness) seem to be negatively correlated with each other

and distance to wattle appears to influence the species communities in the CNR and benchmark grasslands, but not as much in the CFP treatment. In Site 2, most of the CFP plots are on the east facing slopes, potentially influencing the patterns I observe. In CNR plots, bare soil cover and distance to shola influence the community composition.

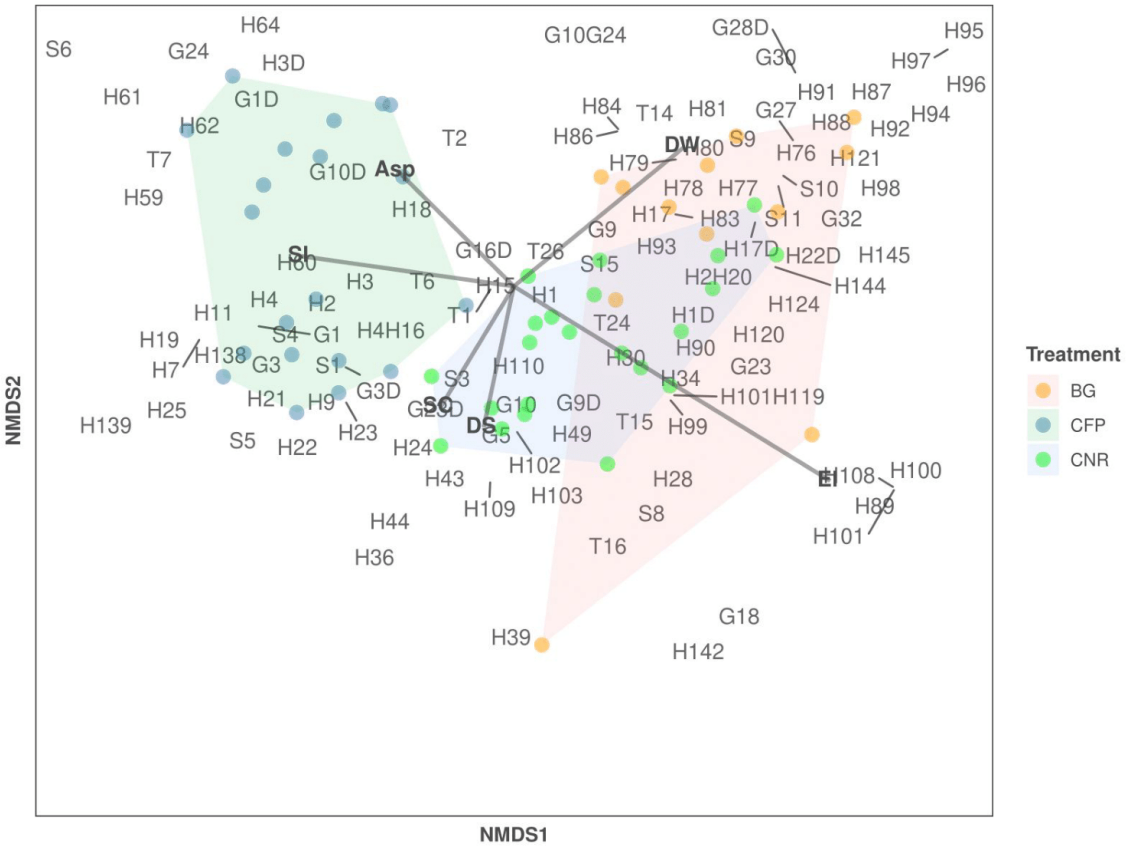

Figure 19. NMDS ordination of plant communities in CFP, CNR and benchmark grassland plots with environmental predictors
El: Elevation, Asp: Aspect (Eastness), Sl: Slope, SC: Bare Soil Cover, DS: Distance to Shola, DW: Distance to Wattle

Black Wattle Density and Regeneration across Plots and Treatments

I noted a significant difference in total wattle counts in wattle plots across sites 1 and 2 and sites 2 and 4. This pattern is only reflected when comparing the 16-30 cm GBH class in sites 1 and 4 and the <= 15 cm GBH class in sites 2 and 4. I found no significant difference between sites for the other GBH classes (Figures 20, and 21).

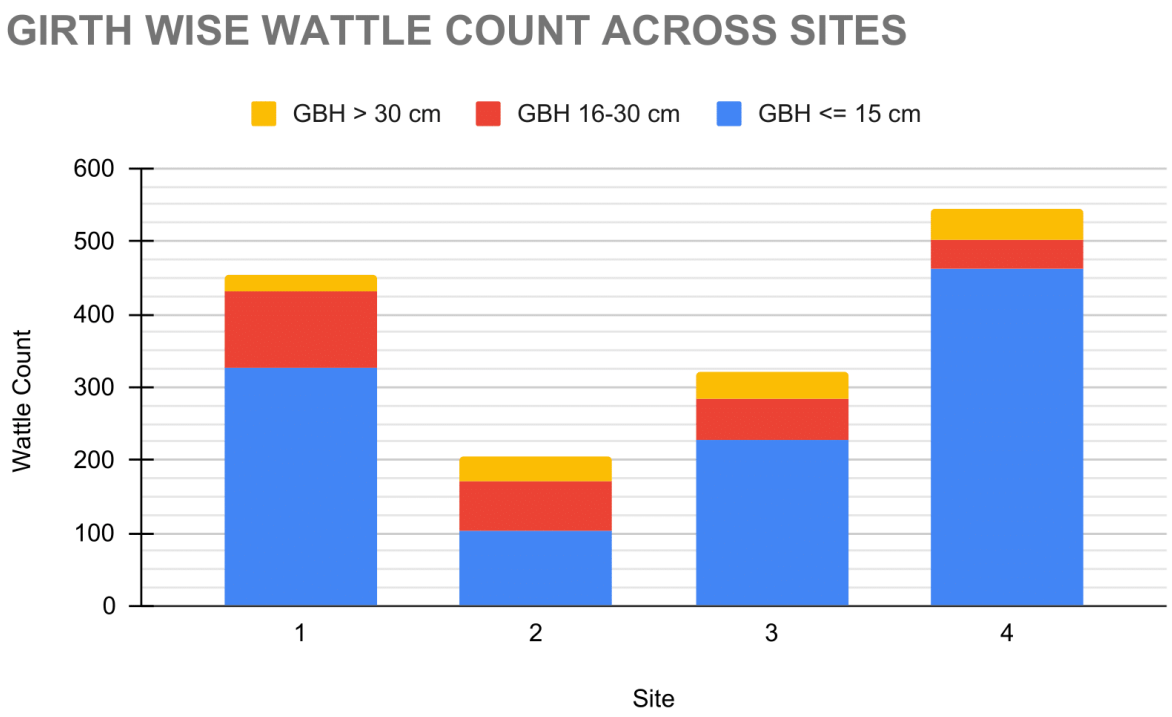

Figure 20. Total and girth wise wattle count in wattle plots across sites

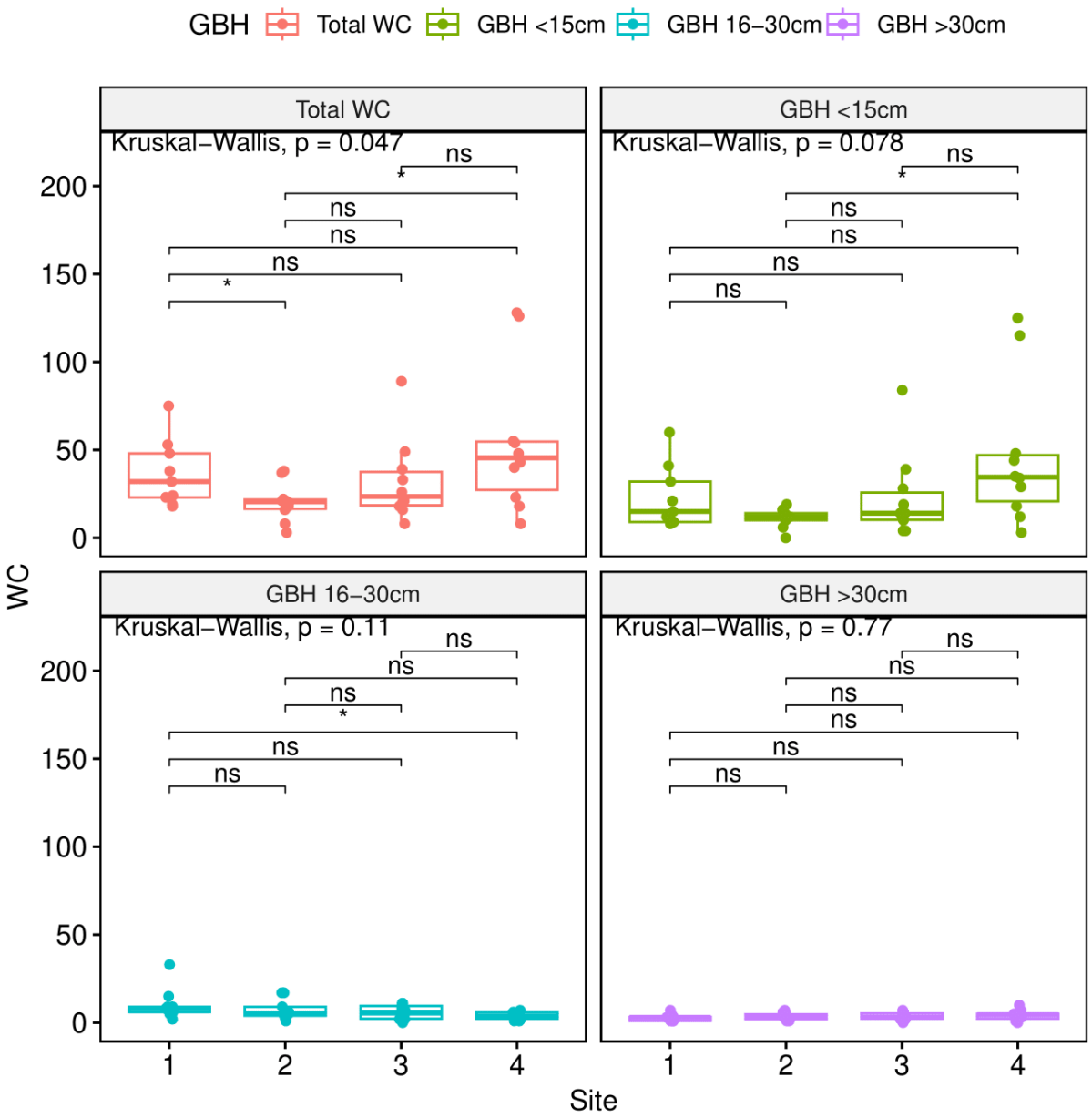

Figure 21. Statistical comparison of wattle plots by total wattle count and girth classes

I observed lowest wattle regeneration in the benchmark grassland plots, but this was not significantly lower than wattle regeneration in the CFP treatment plots when considering all height classes. Interestingly, CNR plots had significantly higher regeneration than both benchmark grassland and CFP plots. When the height classes of the regeneration are considered, I noted a significant difference in wattle regeneration between both treatments and benchmark grasslands in the <= 15 cm height class. These differences between CFP and CNR, and CNR and benchmark grassland plots only remained in the 16-60 cm height class and this could be related to the number of weedings per year and the total number of weeding years (2, 3 or 5 years) (Figures 22 and 23).

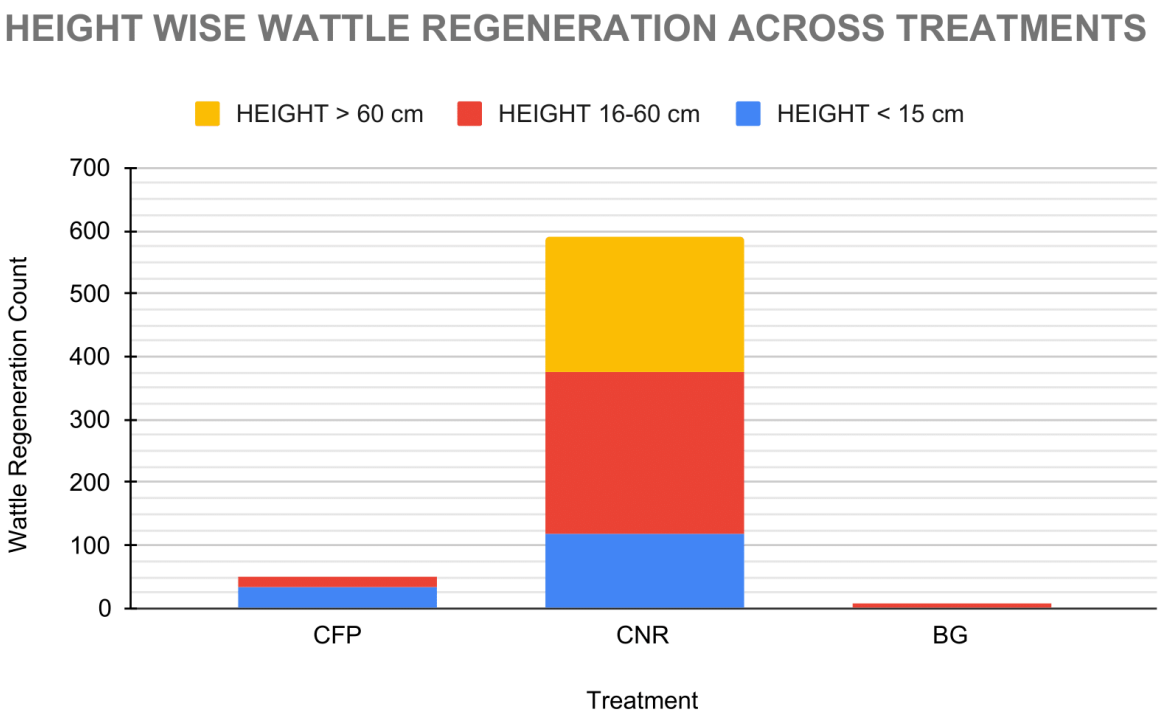

Figure 22. Total and height wise wattle regeneration count in treatment and benchmark grassland plots

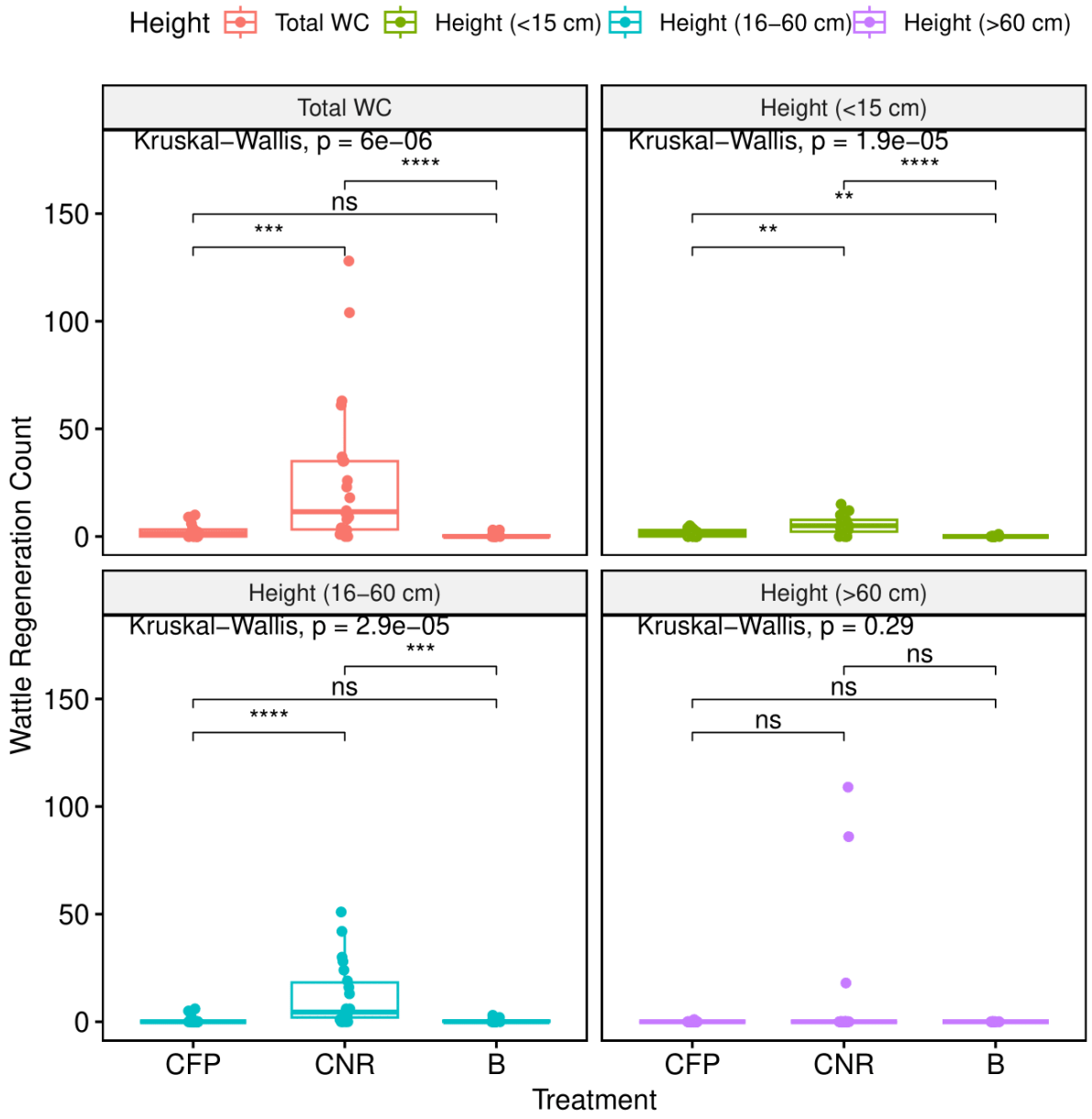

Figure 23. Statistical comparison of treatment and benchmark grassland plots by total wattle regeneration count and height class

Observations on faunal activity in the study area

A few observations on faunal activity in the study area are noteworthy as a potential indicator of the success or status of the restoration processes initiated here. Based on indirect evidence like dung/pellets/scat and information shared by forest field staff, I noted that gaur (*Bos gaurus*) and sambar (*Rusa unicolor*) were frequently using the CFP-treated Site 1 in Pazhathottam, whereas the CFP Site 2 in Pattiyankal was actively used only by sambar. The

CNR-treated site at Bendar (Site 3) was frequented by gaur while in Idalimotta (Site 4; CNR) and the benchmark grasslands, there was direct and indirect evidence of gaur, sambar, Northern Red Muntjac (*Muntiacus vaginalis*) and Bengal Tiger (*Panthera tigris tigris*). Elephants are not common in the study area other than the Idalimotta area (Site 4; CNR) in Anamudi Shola NP, but a female adult Asian elephant (*Elephas maximus*) and a calf was spotted browsing in the Pazhathottam (CFP Site 2) treatment area for the first time in February, 2023.

Among avifauna, Nilgiri Pipits (*Anthus nilghiriensis*) were sighted quite frequently in all the restoration sites except in Pattiyankal (which was at 1900-2000 m while others were above 2200 m). I observed active nests of two vulnerable species endemic to grasslands - the Nilgiri Pipit and the Broad-tailed Grassbird (*Schoenicola platyurus*) in the benchmark grassland near Bendar (Tyler, 2020, Krishnan, 2021). The Broad-tailed Grassbird was never seen or heard in any of the treatment sites. The vulnerable shola forest endemic, White-bellied Sholakili (*Sholicola albiventris*), and the Black and Orange Flycatcher (*Ficedula nigrorufa*) were frequently seen inside black wattle plantations in Pazhathottam (CFP Site 1) and Bendar (CNR Site 3) where the shola forests are within about 400 m. This validates similar observations of the White-bellied Sholakili in wattle plantations contiguous to shola forests (Collar, 2020). A White-bellied Sholakili nest with two nestlings was located in my field station in Idalimotta which was surrounded by black wattle and eucalyptus plantations and further away from shola patches. Their nesting behaviour and utilisation of plantations needs to be understood better (Robin, n.d.). Previous records of the Black and Orange Flycatcher in wattle plantations could not be found and is hence an interesting observation (Clement, 2020). The Indian Peafowl (*Pavo cristatus*) was commonly seen in Bendar (CNR Site 3). Local people and forest watchers said that they started appearing in the area only 3-4 years ago. Throughout India and especially in Kerala, peafowls have expanded their range (SoIB, 2020) and studies suggest that it is an indicator of changing pre-monsoon and post-monsoon rainfall patterns and an increase in temperature and drier conditions in Kerala (Nameer, 2020).

How do local communities perceive this restoration ?

I also collected anecdotal evidence on the local community's dependence on the alien and invasive species being removed, which includes black wattle and eucalyptus (e.g. *E. grandis*) to understand their perception of these restoration interventions. The availability of black wattle for firewood has drastically reduced for the Muthuvan adivasi settlement within the protected areas (Kumar, 2017). In the meantime, penetration of LPG cylinders has improved although usage is variable and limited in most cases, especially among Muthuvans. The key factor here is the availability of *Eucalyptus sp.* that now acts as the major source of firewood and as construction material for the adivasis and the tamil-origin farmers (Raj, 2005). So, while there was no animosity towards the forest department for reduced availability of black wattle and there is a positive perception of grasslands returning as they may help in reducing crop damage by wildlife, eucalyptus acting as a readily available substitute that has not yet been removed, could be critical to the sustenance of this perception. Simultaneously, there is a negative connotation associated with *E. grandis* as the water guzzler that has affected the hydrology of the area, reduced water available for farming in the streams and soil and has affected agricultural yield (Casson, 2004, Kaur and Monga, 2021). Thus, while there is high dependence on eucalyptus sp. there is a demand for its removal as well (Kallarackal, 2010).

Another layer that adds to this perception is the issue of unsettled land rights in public and private land and the resultant conflicts like allegations of encroachment and land grabbing. Large tracts of land were brought under eucalyptus in the 1990s illegally due to the lure of easy money associated with eucalyptus based timber and pulpwood sales. In many cases these lands are owned by absentee landlords from other districts of the state who are seen as 'outsiders' who make disproportionate gains out of the timber business at the cost of the local community who used to own these lands earlier. As a result, the support for eucalyptus is equivocal and dependent on socio-economic standing (Rammohan et al., 2015). The current policy of the government is to encourage the removal of eucalyptus and increase farming area or native vegetation cover outside forests, but the costs and benefits of eucalyptus as an exotic species and as a material resource are inequitably distributed among stakeholders like the local community and 'outsider' absentee landlords (Haran, 2014, Prabhakar, 2010).

Chapter 6

Discussion and Recommendations

In summary, three years after the initiation of restoration interventions, the current status of CNR treatment sites are more similar to benchmark grasslands in terms of plant community composition compared to the sites under CFP treatment. That wattle regeneration in CFP is lower than CNR treatment sites counts in favour of the former as a desired outcome of restoration. The frequency and richness of native grass species and associated herbs is also higher in CNR in comparison to CFP sites. At the same time, invasive species like *Ageratina adenophora, Pteridium aquilinum, Xerochrysum bracteatum* and *Erigeron karvinskianus* are commonly found in both treatment sites and this indicates that methods to target these species also need to be devised to develop site-specific restoration strategies that are sustainable and effective ecologically. The strongest environmental predictors that differentiated the plant communities in CFP-treated sites from benchmark grasslands were elevation and eastness.

Although treatment sites were more similar to benchmark grasslands compared to wattle plantations, there is considerable overlap between the plant communities found in wattle and treatment sites. Wattle invasion into shola forests has been recorded, but the opposite has also been observed in neighbouring Kodaikanal area (Bob and Tanya, 2014). This was confirmed to be the case here as well by forest personnel and could be a subject for further examination in this region. I also recorded a number of grass species in wattle plots, although this varies across and within sites. Thus, wattle plantations with a good amount of native species regeneration need not be restored and may be left as they are for natural recovery. The impact and relevance of a particular treatment may vary based on the history of plantation management before restoration, local climate and fire regime, wattle density and invasion intensity, availability of funds and labour, and efficiency in implementation. Despite the possibility of random effects on the ecological response due to many such factors which were not studied in detail, the cost incurred for CFP seems to be very high given the ecological status as of now, but further research and long-term monitoring and evaluation can only lead us to conclusions.

The ecological response of native species to restoration interventions

The ecological response of a site to a set of restoration interventions is strongly determined by its management (Cheney et al., 2020). These include the restoration goals, nature of implementing agencies, regularity of operations, operating policies and rules, managerial commitment and the sustained availability of adequate funds. In Pattiyankal (Site 2) for example, although the goal was restoration as an experiment that followed an accidental fire in 2015, operations were not implemented in an organised manner or with regularity, due to inadequate funds, changes in management and the absence of a concerted ecorestoration policy in 2015-16. Similarly in Bendar (Site 3), the primary goal was to remove black wattle in order to reduce fire hazard along the state border. Thus, different patches were cleared at different periods of time, and forest personnel also admitted that operations are not always implemented as recorded in the plantation journals due to several challenges.

The frequency of all native grass species was higher in CNR plots when compared to CFP plots. Moreover, I also noted native herbs, shrubs and trees more frequently in CNR plots. This could reflect the presence of these native species in shola forests and wattle plots adjacent to my CNR plots (*pers observ*). Also, the impact of the treatments on soil nutrient and microbial composition due to treatments e.g. clear-felling black wattle (a strong nitrogen fixer) and controlled burning may be investigated as an extension to this work (Grove et al., 2015). Nsikani et al. (2018) recommends removing the clear-felled biomass, to reduce soil nutrients and aid in native species establishment in these cases, but this was not possible across treatments due to legal and logistical challenges. This may have implications for the success of both treatments.

My analysis of plant community composition using NMDS ordination also clearly indicates that the CNR-treated community is more similar to the benchmark grasslands when compared to the CFP-treated community. The higher share of native species especially grasses and, counterintuitively, presence of a few invasive species seem to play a role in creating this pattern. This is seen in the species frequency analysis as well. Elevation, bare soil cover and distance to wattle and to the shola appear to be important in promoting a community that resembles the benchmark grassland community. These are important considerations when deciding on restoration methods and strategies (Srinivasan et al., 2015).

At the same time, some of these observations could be influenced due to undersampling and other random effects. For example, in CFP samples, increased weeding of *Pteridium aquilinum* and its resultant lower frequency or abundance and its uncontrolled presence in benchmark grasslands could make them more dissimilar to each other while CNR seems to be more similar. Thus, such specific cases have to be studied further to assess the success of these treatments.

Similarly, one has to look at site-specific strategies and the stage of succession of the plant communities in these treatment sites which is a matter for long-term monitoring and evaluation before passing a judgement on the suitability of different treatments to restore shola grasslands in this landscape. Some of the factors based on which site-specific decisions and treatments may be devised are - the stage of the wattle stock, whether it is a plantation area or an invaded space and plant community composition in the wattle especially in terms of native grasses and invasives. The protection of relatively intact grasslands with invasive wattle fronts in the surrounding area need to be prioritised over the restoration of old, mature wattle stands with good native species regeneration. It is also recommended to assess invasion intensity and native species regeneration in the undergrowth of wattle plantations to know whether to restore a particular site.

Role of weeding on black wattle regeneration and the risk of planting non-native grasses

I recorded significantly higher black wattle regeneration in CNR-treated plots when compared to CFP-treated plots and a wider range of height classes (16-60 cm and >60 cm) in addition to the seedlings (<= 15 cm high). This might reflect the influence of regular accidental fire events in promoting natural wattle regeneration and vitally, the importance of sustained and intensive weeding in CNR, even though fire is not used in this treatment (Grace et al., 2001, DiTomaso et al., 2006). Weeding was rarely practised after 2-3 years (depending on the site) in CNR-treated sites. I also noted a higher prevalence of black wattle coppices in CNR-treated sites (especially Site 4); this was not the case in CFP sites where wattles regenerated from seeds (KFD staff; *pers comm.*). I was unable to quantify this during my sampling and could be an important consideration while planning regeneration activities. Hence, site managers need to plan for a sustained availability of labour and funds for

maintenance activities like weeding or controlled burns to improve the odds of a successful restoration.

As CNR may not have succeeded in the sites where CFP was applied, it might be necessary to include techniques in CFP to introduce native species communities with functional traits similar to benchmark grasslands like palatability, response to fire and tolerant to invasive species of non-natives that were used (Funk et al., 2008, Wigley et al., 2021). But I noted that the KFWD introduced non-native grasses like *Digitaria sanguinalis* (Site 2) and *Cynodon dactylon* (Site 1) in the CFP-treated sites for the rapid establishment of grass cover. Similarly in Idalimotta (Site 4; CNR treatment), *Cenchrus clandestinus* was used in a few patches for aesthetic purposes, although I did not encounter these frequently during my sampling. *C. dactylon* is known to be drought tolerant, alters fire regimes and ecosystem functions (CABI, 2014) and recovers quickly after fire (Cook et al., 2005); *D. sanguinalis* is also tolerant to fire (Areces-Berazain, 2022). Perry et al. (2010) and Coutinho et al. (2019) recommend using fast-growing native grasses to sequester nutrients rapidly followed by their removal to reduce soil nutrients, outcompete invasives and aid in establishment of native grassland communities. This is not the case here since none of these species are native to the shola grasslands and they were not removed when I conducted my study. Whether these species are persisting or acting as a weed and affecting the arrival and establishment of native perennial grasses and other species (Nerlekar and Veldman, 2020), needs to be studied in these CFP plots.

Alien and secondary invasive species in the restoration sites and their response to fire

Among invasive species, I encountered *Ageratina adenophora* more frequently in CFP-treated plots when compared to CNR-treated and benchmark grassland plots; this species is known to be tolerant to fire and resprouts easily post-fire events (Slotwinski, 2002). Hence, weeding intensity may have to increase or fire may not be the right method where this species is already dominant. On the other hand, I encountered *Pteridium aquilinum* or bracken fern and *Erigeron karvinskianus* more frequently in CNR and benchmark samples than in CFP-treated sites. The former could be a case of undersampling as Bracken is considered to be fire adapted and even promotes fire (Crane et al., 1990). The influence of *E. karvinskianus* needs to be studied further as it can suppress young plants in replanting areas

by forming dense mats (Hind, 2012) and produces a large number of wind dispersed seeds thus potentially making it a serious concern in restoration projects (Hannah et al., 2019). *Ageratum conyzoides* was common only in CFP sites. It is not tolerant to fire but is a prolific seeder and is known to be unaffected by herbivory as it is unpalatable. (CABI, 2016, Kaur, 2011) *Rubus ellipticus*, which is a native to shola margins but tends to take over cleared areas, was also more common in CNR-treated plots but it is known to regenerate strongly from underground shoots after fire (Swearingen, 2009, GISD, 2023). The frequency of non native species like *Eragrostis viscosa* and *Xerochrysum bracteatum* was higher in CNR compared to CFP plots. *Eucalyptus sp.* and *A. mearnsii* also increase fire hazards. In the study area, black wattle stands were burnt in 2015 and 2019 due to fires whose origins are unclear. Fire fighters with the KFWD observed that the dry leaves and branches in black wattle crown aid in spreading fire from one plantation to the other across fire breaks, often converting ground fires to crown fires and thus increase the extent and intensity of damage due to fire.

Thus, even though controlled burning followed by regular weeding is known to be an effective method to remove black wattle and secondary invasions (Nsikani et al., 2019, Sriramamurthy, 2020), the response of other alien and invasive species to fire, weeding and competition as a result of planting may have to be considered to improve restoration outcomes.

Assessing the cost effectiveness and socio-economic aspects of the restoration interventions

My assessment of the background information on the sites and management interventions indicates that the CNR treatment (which is more passive) was used in areas with lower invasion intensity. In areas where the invasion intensity was relatively higher, the CFP approach, which is more active, was used. This is understood to be the right strategy (Buisson et al., 2019, Raghurama and Sankaran, 2021). From the previous sections, it is clear that the ecological gains in terms of native species richness and frequency is currently higher in CNR than CFP. Moreover, my plant community assessments suggest that the CNR-treated sites resemble the benchmark grasslands better than the CFP-treated sites. Regular intensive weeding and controlled burning has resulted in lower wattle regeneration in CFP sites but it also led to higher cost. Because of the nature and number of methods involved, CNR is more

feasible logistically as well. Although not investigated thoroughly, observations of native bird and herbivore presence and activity was markedly higher in CNR sites.

The CFP project in Pazhathottam (Site 1) incurred a cost of INR 5.46 lakhs per hectare which is 150% higher than the INR 2.17 lakhs per hectare cost of the CNR treatment in Idalimotta (Site 4). But it has to be acknowledged that these costs are also a function of the intensity and type of interventions made and effort involved in terms of the number of people employed over time for different operations which was definitely higher for CFP in Site 1. In Pazhathottam, a higher number of wage labourers from among the local tamil-origin farming community and Muthuvan adivasi settlements were employed and continue to be engaged in the restoration process at a rate of INR 793 / day. In the CNR site, a far lower number of people were involved for a shorter duration. An Eco-Development Committee (EDC) named Haritha Vasantham has also been formed in Pazhathottam constituted by the forest department personnel and the local community (Lekshmi, 2020). Local community welfare and their participation as a key actor and stakeholder in the initiative needs to be considered as a socio-economic gain of restoration. It has given a source of income for a minimum of 20 youths in the neighbourhood of Pazhathottam and may play a role in the sustenance of the interventions and thus increase its cost effectiveness (Kannan et al., 2016).

On the other hand, for implementation of restoration interventions for black wattle and outside forests where eucalyptus is the major player, localised nuances like the land-based conflicts mentioned earlier, provide ways to look critically at alien and invasive species ecology, through the lens of political ecology. Removal of exotic or invasive species which are material resources for the local community should not lead to the unfair distribution of the costs and benefits of such interventions among different stakeholders. Their informed consent to participate and a rights-based role in decision-making related to restoration activities is also necessary. In this context, the status of implementation of Forest Rights Act (FRA) needs to be highlighted. Though recognition of Individual Forest Rights (IFR) have been completed, Community Forest Rights (CFR) have not been recognised. Respondents from the Muthuvan adivasi community did not generally complain of restricted access to forest areas and resources. But the fact that local community participation is mostly limited to livelihood opportunities under the EDC mechanism (an extension of the Joint Forest Management (JFM) scheme for protected areas), suggests the absence of a rights-based approach of participation and that they were not decision-makers for the restoration interventions. Effective implementation of the FRA that can potentially enable the

forest dwellers to manage and plan interventions in their Community Forests, could prove to be a game changer in deciding why, what, how, and when to restore or not and lead to better outcomes.

I conclude by asserting the importance of long-term research and monitoring of these restoration treatments using indicators of biodiversity recovery, soil characteristics, and ecosystem functions like water and nutrient cycling and welfare of the local community, as a return to the community assembly of a benchmark grassland may take centuries.

Limitations of my study

I conducted fieldwork from April 17th to May 25th, which made species identification for some plant groups like grasses challenging, which flower post-monsoon. Despite my best efforts and the inputs of multiple experts, I cannot rule out the possibility of a few misidentifications. I could only locate two sites corresponding to the two treatments I chose to investigate. I was also constrained in sampling no more than ten wattle and ten treatment plots for each site because of the limited time I had to conduct fieldwork. I estimated species richness using species accumulation curves but none of the curves flattened indicating the need for additional sampling for each plot type. The species accumulation curves were flatter when comparing CFP and CNR treatments, but this was not the case for the benchmark grassland plots since I could not find sufficient sites for additional sampling. I collected data on plant species counts and cover, but converted this to presence-absence data for data operability and simplifying data analysis; this limits my findings to species frequency and richness. The abundance data could be used to pursue additional analysis of plant community composition, dominance, distribution, importance value etc to get more meaningful information. These data can also be used to compare the abundance of invasive species versus native and endemic ones across treatments and the benchmark grassland plots.

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Annexures

Annexure 1. Sample datasheet for wattle plots

SITE	TREATMENT	PLOT TYPE	P. NO.	SPECIES CODE & PRESENCE-ABSENCE								ENVIRONMENTAL VARIABLES						WATTLE STOCK IN WATTLE PLOTS					
				G1	G2	H1	H2	S1	S2	T1	T2	Elevation (m)	Aspect (sine)	Slope (sine)	Soil Cover	Distance to Shola (m)	Canopy Cover Index	Wattle Count	GBH (<=15 cm)	GBH (16-30 cm)	GBH (>30 cm)	Height (m)	Age (yr)
1	Fire and Planting	Wattle	1W1	0	0	0	0	0	0	0	0	2,279.40	-0.0174	0.0872	0.95	200.00	44.85	53.00	41.00	9.00	3.00	6.00	4.00
1	Fire and Planting	Wattle	1W2	0	0	0	0	0	0	0	0	2,301.40	-0.9063	0.1392	0.95	250.00	44.20	289.00	277.00	12.00	0.00	6.00	4.00
1	Fire and Planting	Wattle	1W3	0	0	1	0	0	0	0	0	2,377.74	0.3420	0.2419	0.95	300.00	57.20	32.00	21.00	7.00	4.00	6.00	4.00
1	Fire and Planting	Wattle	1W4	0	0	0	0	1	0	0	0	2,357.74	0.5736	0.0872	0.80	500.00	60.91	75.00	60.00	15.00	0.00	6.00	4.00
1	Fire and Planting	Wattle	1W5	0	0	1	0	1	0	0	0	2,377.64	0.7660	0.3584	0.70	150.00	64.49	19.00	9.00	9.00	1.00	6.00	4.00
1	Fire and Planting	Wattle	1W6	0	0	1	0	1	0	1	0	2,412.10	-0.9848	0.2079	0.70	250.00	73.69	24.00	9.00	6.00	3.00	6.00	4.00
1	Fire and Planting	Wattle	1W7	0	0	1	0	1	0	1	0	2,416.60	-0.9925	0.2419	0.70	450.00	61.32	23.00	12.00	8.00	3.00	6.00	4.00
1	Fire and Planting	Wattle	1W8	1	0	0	0	1	0	1	0	2,374.90	0.0175	0.1392	0.90	500.00	63.66	48.00	8.00	33.00	7.00	6.00	4.00
4	Natural Regeneration	Wattle	4W1	0	0	1	0	1	0	0	0	2,472.43	0.0698	0.2079	0.05	180.00	62.26	40.00	35.00	1.00	4.00	8.00	8.00
4	Natural Regeneration	Wattle	4W2	0	0	1	0	1	0	0	1	2,488.02	-0.5299	0.0872	0.05	170.00	75.44	8.00	3.00	2.00	3.00	8.00	8.00
4	Natural Regeneration	Wattle	4W3	0	0	0	0	1	0	0	0	2,485.22	-0.3746	0.1045	0.05	100.00	82.64	43.00	29.00	7.00	7.00	8.00	8.00
4	Natural Regeneration	Wattle	4W7	0	0	0	0	1	0	0	0	2,480.03	0.4540	0.2079	0.05	200.00	53.83	128.00	125.00	3.00	0.00	8.00	8.00
4	Natural Regeneration	Wattle	4W8	0	0	1	0	1	0	0	0	2,510.72	0.4384	0.1564	0.05	100.00	60.82	126.00	115.00	6.00	5.00	8.00	8.00
4	Natural Regeneration	Wattle	4W9	0	0	1	0	1	0	0	1	2,519.92	0.0349	0.2419	0.00	60.00	59.40	54.00	48.00	5.00	1.00	8.00	8.00
4	Natural Regeneration	Wattle	4W10	0	0	1	0	1	0	0	1	2,477.33	-0.1564	0.1564	0.05	80.00	66.93	23.00	18.00	3.00	2.00	8.00	8.00

Annexure 2. Sample datasheet for restoration plots

SITE	TREATMENT	PLOT TYPE	P. NO.	SPECIES CODE & PRESENCE-ABSENCE								ENVIRONMENTAL VARIABLES						WATTLE REGENERATION IN RESTORATION PLOTS				
				G1	G2	H1	H2	S1	S2	T1	T2	Elevation (m)	Aspect (sine)	Slope (sine)	Soil Cover	Distance to Shola (m)	Distance to Wattle (m)	Wattle Count	Height (<=15 cm)	Height (16-60 cm)	Height (>60 cm)	GBH (<15 cm)
1	Fire and Planting	Restoration	1R1	0	0	0	0	0	0	0	0	2,261.34	0.0698	0.4067	0.00	60.00	15.00	2.00	2.00	0.00	0.00	2.00
1	Fire and Planting	Restoration	1R2	0	0	0	0	0	0	0	0	2,282.10	-0.7880	0.3090	0.00	100.00	80.00	0.00	0.00	0.00	0.00	0.00
1	Fire and Planting	Restoration	1R3	0	0	1	0	0	0	0	0	2,286.90	0.0000	0.3907	0.00	300.00	10.00	1.00	1.00	0.00	0.00	1.00
1	Fire and Planting	Restoration	1R4	0	0	0	0	1	0	0	0	2,315.00	0.7431	0.2079	0.40	400.00	100.00	0.00	0.00	0.00	0.00	0.00
1	Fire and Planting	Restoration	1R5	0	0	1	0	1	0	0	0	2,348.00	0.0000	0.1045	0.30	250.00	20.00	2.00	2.00	0.00	0.00	2.00
1	Fire and Planting	Restoration	1R6	0	0	1	0	1	0	1	0	2,327.00	0.7880	0.2756	0.30	160.00	60.00	0.00	0.00	0.00	0.00	0.00
1	Fire and Planting	Restoration	1R7	0	0	1	0	1	0	1	0	2,319.34	0.2756	0.3090	0.00	120.00	40.00	0.00	0.00	0.00	0.00	0.00
1	Fire and Planting	Restoration	1R8	1	0	0	0	1	0	1	0	2,281.50	-0.0872	0.3746	0.05	15.00	70.00	2.00	2.00	0.00	0.00	2.00
1	Fire and Planting	Restoration	1R9	1	0	0	0	1	0	1	0	2,302.00	-0.3746	0.3907	0.00	70.00	50.00	0.00	0.00	0.00	0.00	0.00
1	Fire and Planting	Restoration	1R10	0	0	1	0	1	0	0	0	2,186.00	-0.7547	0.3256	0.00	40.00	70.00	1.00	1.00	0.00	0.00	1.00
4	Natural Regeneration	Restoration	4R1	0	0	1	0	1	0	0	0	2,476.52	-0.0698	0.2756	0.00	120.00	50.00	104.00	5.00	13.00	86.00	104.00
4	Natural Regeneration	Restoration	4R2	0	0	1	0	1	0	0	1	2,500.01	0.3907	0.2588	0.00	150.00	20.00	128.00	3.00	16.00	109.00	128.00
4	Natural Regeneration	Restoration	4R3	0	0	0	0	1	0	0	0	2,481.02	0.6691	0.4695	0.00	50.00	60.00	23.00	2.00	3.00	18.00	23.00
4	Natural Regeneration	Restoration	4R4	0	0	0	0	1	0	0	0	2,464.72	-0.2588	0.1219	0.05	10.00	90.00	0.00	0.00	0.00	0.00	0.00
4	Natural Regeneration	Restoration	4R5	0	0	1	0	1	0	0	1	2,467.32	-0.1908	0.1908	0.05	60.00	100.00	1.00	0.00	1.00	0.00	1.00
4	Natural Regeneration	Restoration	4R6	0	0	1	0	1	0	0	1	2,454.53	0.1392	0.4848	0.00	40.00	60.00	3.00	1.00	2.00	0.00	3.00
4	Natural Regeneration	Restoration	4R7	0	0	0	0	1	0	0	0	2,415.44	0.8090	0.2588	0.00	80.00	80.00	26.00	7.00	19.00	0.00	26.00
4	Natural Regeneration	Restoration	4R8	0	0	1	0	1	0	0	0	2,427.54	-0.0523	0.1564	0.20	200.00	90.00	63.00	15.00	42.00	0.00	63.00
4	Natural Regeneration	Restoration	4R9	0	0	1	0	1	0	0	1	2,394.14	0.4540	0.0872	0.10	60.00	40.00	35.00	10.00	28.00	0.00	35.00
4	Natural Regeneration	Restoration	4R10	0	0	1	0	1	0	0	1	2,343.04	0.0698	0.2588	0.00	50.00	50.00	37.00	7.00	30.00	0.00	37.00

Annexure 3. Sample datasheet for benchmark grassland plots

SITE	TREATMENT	PLOT TYPE	P. NO.	SPECIES CODE & PRESENCE-ABSENCE								ENVIRONMENTAL VARIABLES						WATTLE COUNT IN BENCHMARK GRASSLAND PLOTS				
				G1	G2	H1	H2	S1	S2	T1	T2	Elevation (m)	Aspect (sine)	Slope (sine)	Soil Cover	Distance to Shola (m)	Distance to Wattle (m)	Wattle Count	Height (<=15 cm)	Height (16-60 cm)	Height (>60 cm)	GBH (<15 cm)
1	NA	Benchmark	1B1	0	0	1	0	0	0	0	0	2,355.34	-0.3907	0.0872	0.30	200.00	10.00	0.00	0.00	0.00	0.00	0.00
3	NA	Benchmark	3B1	0	0	0	0	0	0	0	0	2,538.50	0.4226	0.2079	0.00	50.00	80.00	0.00	0.00	0.00	0.00	0.00
3	NA	Benchmark	3B2	0	0	0	0	0	0	0	0	2,507.77	-1.0000	0.3907	0.00	20.00	60.00	2.00	0.00	2.00	0.00	2.00
3	NA	Benchmark	3B3	0	0	0	0	0	0	0	0	2,510.27	-0.9848	0.2419	0.00	120.00	100.00	3.00	0.00	3.00	0.00	3.00
3	NA	Benchmark	3B4	0	0	0	0	0	0	0	0	2,489.87	-0.9994	0.1045	0.00	40.00	100.00	0.00	0.00	0.00	0.00	0.00
3	NA	Benchmark	3B5	0	0	0	0	1	0	0	0	2,497.37	-0.2079	0.0698	0.00	150.00	60.00	0.00	0.00	0.00	0.00	0.00
3	NA	Benchmark	3B6	0	0	0	0	0	0	0	0	2,468.26	-0.4226	0.2419	0.00	50.00	200.00	0.00	0.00	0.00	0.00	0.00
3	NA	Benchmark	3B7	0	0	0	0	0	0	0	0	2,494.16	-0.1736	0.1392	0.00	30.00	180.00	0.00	0.00	0.00	0.00	0.00
3	NA	Benchmark	3B8	0	0	0	0	0	0	0	0	2,486.47	0.5736	0.1219	0.00	40.00	50.00	0.00	0.00	0.00	0.00	0.00
3	NA	Benchmark	3B9	0	0	0	0	0	0	0	0	2,514.97	-0.8660	0.0872	0.00	50.00	100.00	0.00	0.00	0.00	0.00	0.00
3	NA	Benchmark	3B10	0	0	0	0	0	0	0	0	2,516.97	-0.9272	0.0523	0.00	70.00	120.00	3.00	1.00	2.00	0.00	3.00
4	NA	Benchmark	4B1	0	0	0	0	1	0	0	0	2,242.99	-0.8988	0.2079	0.00	30.00	40.00	0.00	0.00	0.00	0.00	0.00

Annexure 4. Checklist of species sampled and identified in the study area

No.	Scientific Name	Native (Y/N)	Invasive (Y/N)	RET Status
GRASSES, RUSHES AND SEDGES				
1	*Andropogon lividus*	Y	N	
2	*Cenchrus clandestinus*	N	Y	
3	*Chrysopogon nodulibarbis*	Y	N	
4	*Cymbopogon nardus*	Y	N	
5	*Cyperus flavidus*			
6	*Dichanthium foulkesii*	Y	N	
7	*Eragrostis amabilis*	N		
8	*Eragrostis nigra*	Y	N	
9	*Eragrostis viscosa*			
10	*Isachne kunthiana*	Y	N	
11	*Juncus prismatocarpus*		N	
OTHER HERBS				
1	*Ageratina adenophora*	N	Y	
2	*Ageratum conyzoides*	N	Y	
3	*Anaphalis beddomei*	Y	N	E
4	*Anaphalis meeboldii*	Y	N	E to WG
5	*Anaphalis sp.*			
6	*Anaphalis subdecurrens*	Y	N	E
7	*Anaphalis wightiana*	Y	N	
8	*Arisaema leschenaultia*			
9	*Aristea ecklonii*	N	Y	
10	*Asclepias curassavica*	N	Y	
11	*Asplenium sp.*			
12	*Bidens pilosa*	N	Y	
13	*Brachycorythis wightii*	Y	N	
14	*Cajanus rugosus*			
15	*Centella asiatica*			
16	*Chenopodium album*	N	Y	

No.	Scientific Name	Native (Y/N)	Invasive (Y/N)	RET Status
17	*Commelina hirsuta*	Y	N	R, E to WG
18	*Commelina indehiscens*	Y	N	R (RDB), E to WG
19	*Conyza stricta*	Y	N	
20	*Crassocephalum crepidioides*	N	Y	
21	*Crotalaria scabrella*	Y	N	E
22	*Curculigo orchioides*	Y	N	LR NT (RDB)
23	*Cyanotis arachnoidea*	Y	N	
24	*Dandelion sp.*			
25	*Dandelion sp.*			
26	*Dandelion sp. ?*			
27	*Dodonea chionanthus*			
28	*Droguetia iners*	Y	N	
29	*Eleocharis congesta*	Y	N	
30	*Emilia sonchifolia / scabra*	Y	N	
31	*Erigeron karvinskianus*		Y	
32	*Erigeron sp.*			
33	*Erigeron sp.*			
34	*Eriocoulon robusta*	Y	N	E to SWG
35	*Fragaria nilgerrensis*	Y	N	E to P. India
36	*Gentiana pedicellata*	Y	N	
37	*Gynura nitida*			
38	*Hedyotis ?*			
39	*Hypericum mysorense*	Y	N	
40	*Hypericum sp.*			
41	*Hypochaeris radicata*			
42	*Impatiens balsamina*	Y	N	
43	*Impatiens chinensis*	Y	N	
44	*Impatiens sp.*			
45	*Impatiens tangachee*	Y	N	
46	*Indigofera prostrata*	Y	N	
47	*Justicia simplex*			

No.	Scientific Name	Native (Y/N)	Invasive (Y/N)	RET Status
48	*Laurembergia coccinea*			
49	*Leucas aspera*			
50	*Leucas ciliata*	Y	N	
51	*Lobelia leschenaultiana*	Y	N	
52	*Lysimachia procumbens*	N		
53	*Lysimachia procumbens*			
54	*Micromeria imbricata*	Y	N	N
55	*Oxalis corniculata*	N	Y	
56	*Passiflora foetida ?*	N	Y	
57	*Pogostemon benghalensis*	Y	N	
58	*Polygala sibirica*	Y	N	
59	*Pseudognaphalium hypoleucum*	Y	N	
60	*Pteridium aquilinium*			
61	*Ranunculus reniformis*			
62	*Richardia scabra*	N	Y	
63	*Spermacoce articularis*			
64	*Spiranthes australis*	Y	N	
65	*Striga asiatica*	Y	N	
66	*Thistle*			
67	*Tridax procumbens*	N	Y	
68	*Valeriana sp. ?*			
69	*Veronica plebeia*	N		
70	*Viola betonicifolia*	Y	N	
71	*Viola sp. ?*			
72	*Wahlenbergia marginata*			
73	*Xerochrysum bracteatum*			
SHRUBS				
1	*Clerodendrum infortunatum*	Y	N	
2	*Eurya nitida*	Y	N	
3	*Flemingia sp. grahamiana ?*	Y	N	
4	*Lantana camara*	N	Y	

No.	Scientific Name	Native (Y/N)	Invasive (Y/N)	RET Status
5	*Osbeckia leschenaultiana*	Y	N	E to SWG
6	*Rauvolfia ?*			
7	*Rhododendron arboreum*	Y	N	E to SWG
8	*Rubus ellipticus*	Y	N	
9	*Rubus fairholmianus*	Y	N	
10	*Rubus niveus*	Y	Y	
11	*Rubus sp.*			
12	*Solanum sp / violaceum ?*			
13	*Strobilanthes kunthiana*	Y	N	E to WG
14	*Zanthoxylum asiaticum*	Y	N	
15	*Berberis tinctoria*	Y	N	
TREES				
1	*Acacia mearnsii*	N	Y	
2	*Celtis philippensis*	Y		
3	*Eucalyptus sp.*	N		
4	*Excoecaria crenulata ?*	Y		
5	*Litsea wightiana*	Y		E to SWG
6	*Lobelia nicotianifolia ?*	Y		
7	*Neolitsea scrobiculata ?*	Y		E to WG
8	*Maesa indica*	Y		
9	*Mahonia leschenaultia*	Y		E to WG
10	*Pinus sp.*	N		
11	*Symplocos sp.*			
12	*Syzygium sp.*	Y		